N 62-3-3

U. S. ARMY
TRANSPORTATION RESEARCH COMMAND
FORT EUSTIS, VIRGINIA

TCREC Technical Report 61-121

IAL AIRCRAFT RECOVERY AND EVACUATION SYSTEM

VOLUME I

Project 9R38-01-017-39
Contract DA 44-177-TC-662

March 1962

prepared by :

VERTOL DIVISION
THE BOEING COMPANY
Morton, Pennsylvania

$10.50

HEADQUARTERS
U. S. ARMY TRANSPORTATION RESEARCH COMMAND
Fort Eustis, Virginia

FOREWORD

The report contained herein was prepared by the Vertol Division of the Boeing Company in accordance with stipulations of Contract DA 44-177-TC-662, initiated by the U. S. Army Transportation Research Command, Fort Eustis, Virginia.

The conclusions made by the contractor are concurred in by this Command. Based on these conclusions, recommendations are being made that efforts be concentrated towards perfecting an aerial aircraft recovery and evacuation system. This recommendation reflects views of this Command and not necessarily those of the Chief of Transportation or the Department of the Army.

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Project 9R38-01-017-39
Contract DA44-177-TC-662

AERIAL AIRCRAFT RECOVERY AND EVACUATION SYSTEM

R-260A
Volume I

Prepared by
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for
U. S. ARMY TRANSPORTATION RESEARCH COMMAND
FORT EUSTIS, VIRGINIA

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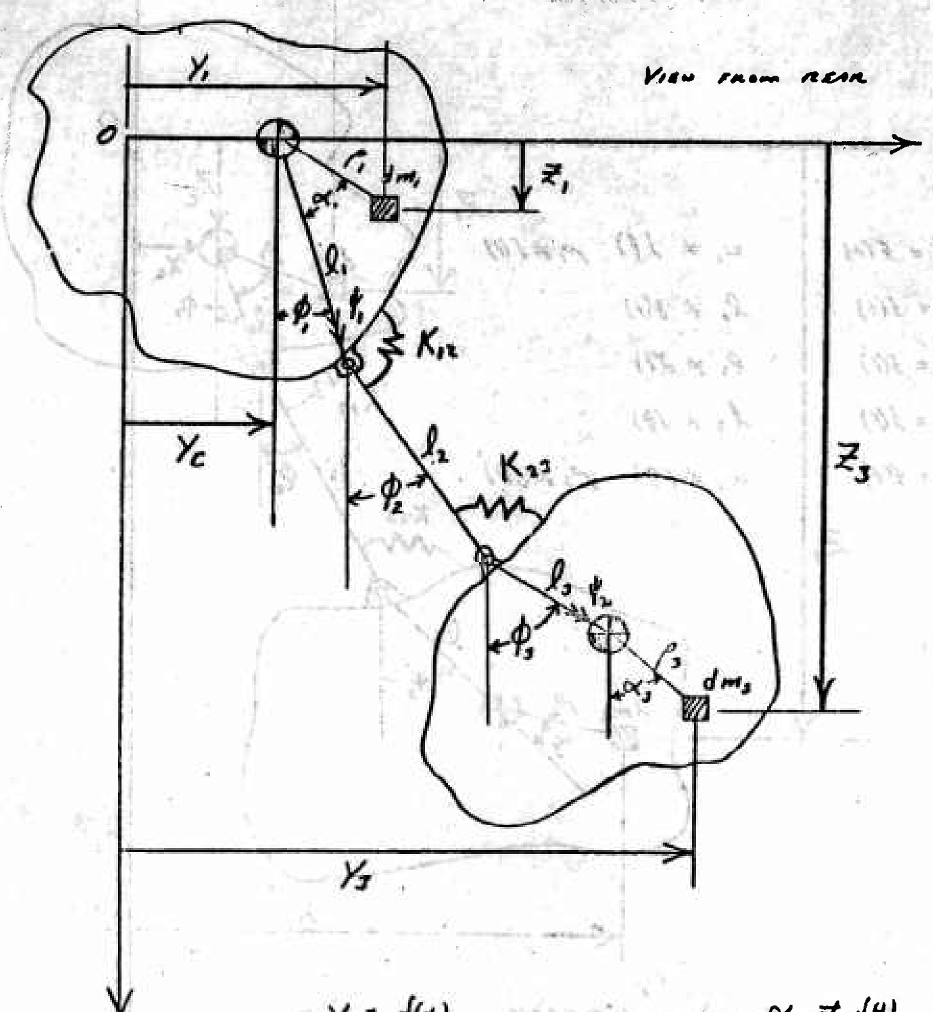
LIST OF SYMBOLS

Symbol	Definition	Units
Θ_o	Root collective pitch	deg
$\Theta_{o_{mean}}$	Mean root collective pitch of both rotors due to collective pitch lever	deg
$\alpha_{fus.}$	Attitude of the fuselage W.L. with respect to the horizontal	deg
δ_{stick}	Longitudinal stick displacement (Aft positive)	in.
$\frac{\partial M_{cg}}{\partial \delta_L} \backsim M_\delta$	Longitudinal control power (Aft stick produces nose up moments)	$\frac{\text{ft-lb}}{\text{in.}}$
$\frac{\partial \mathcal{L}_{cg}}{\partial \delta_s} \backsim \mathcal{L}_\delta$	Lateral control power (Right stick produces right roll)	$\frac{\text{ft-lb}}{\text{in.}}$
$\frac{\partial N_{cg}}{\partial \delta_R} \backsim N_\delta$	Directional control power (Right pedal produces nose right)	$\frac{\text{ft-lb}}{\text{in.}}$
$\frac{\partial \theta_{1\,F,R}}{\partial \delta_R}$	Lateral cyclic due to pedal displacement	$\frac{\text{rad.}}{\text{in.}}$
$\frac{\partial \theta_{1\,F,R}}{\partial \delta_s}$	Lateral cyclic due to later stick	$\frac{\text{rad.}}{\text{in.}}$
$\frac{\partial \theta_{2\,F,R}}{\partial \delta_s}$	Longitudinal cyclic due to long. stick	$\frac{\text{rad.}}{\text{in.}}$
$\frac{\partial \theta_{o\,F,R}}{\partial \delta_s}$	DCP due to longitudinal stick	$\frac{\text{rad.}}{\text{in.}}$
a	Lift curve slope	1/rad.
e	Rotor hinge offset	ft.
A	Rotor disc area (πR^2)	ft.^{2}
σ	Solidity ($\frac{bc}{\pi R}$)	non-dim.
V_t	Rotor tip speed	fps
Ω	Rotor velocity	rpm
ω	Rotor velocity	rad/sec
c	Rotor chord	ft.

Symbol	Definition	Units
R	Rotor radius	ft.
$i_{F,R}$	Rotor shaft incidence (see page 7)	deg.
$I_{F,R}$	Rotor blade flapping inertia about the horizontal flapping pin	Slug-ft.^{2}
$M_{w_{F,R}}$	Weight moment about the horizontal flapping pin	ft-lb
$\left(\frac{F_c e b}{a}\right)_{F,R}$	Hinge moment power	ft-lb
θ_t	Total blade twist	deg.
r_a	Distance from ℄ rotation to root airfoil	ft.
$F_{c_{F,R}}$	Centrifugal force of a rotor blade	lb.
b	Number of rotor blades	
$\ddot{\theta}$	Initial pitch acceleration	deg/sec^2/in.
$\ddot{\phi}$	Initial roll acceleration	deg/sec^2/in.
$\ddot{\psi}$	Initial yaw acceleration	deg/sec^2/in.
$I_{x,y,z,xz}$	Helicopter moments of inertia about the c.g.	slug-ft.^{2}

AIRCRAFT RECOVERY

LATERAL EQUATIONS OF MOTION



$Y_c = f(t)$ $\qquad$ $\alpha_1 \neq f(t)$ $\quad$ $\rho_1 \neq f(t)$

$\phi_1 = f(t)$ $\quad$ $\psi_1 = f(t)$ $\qquad$ $l_1 \neq f(t)$

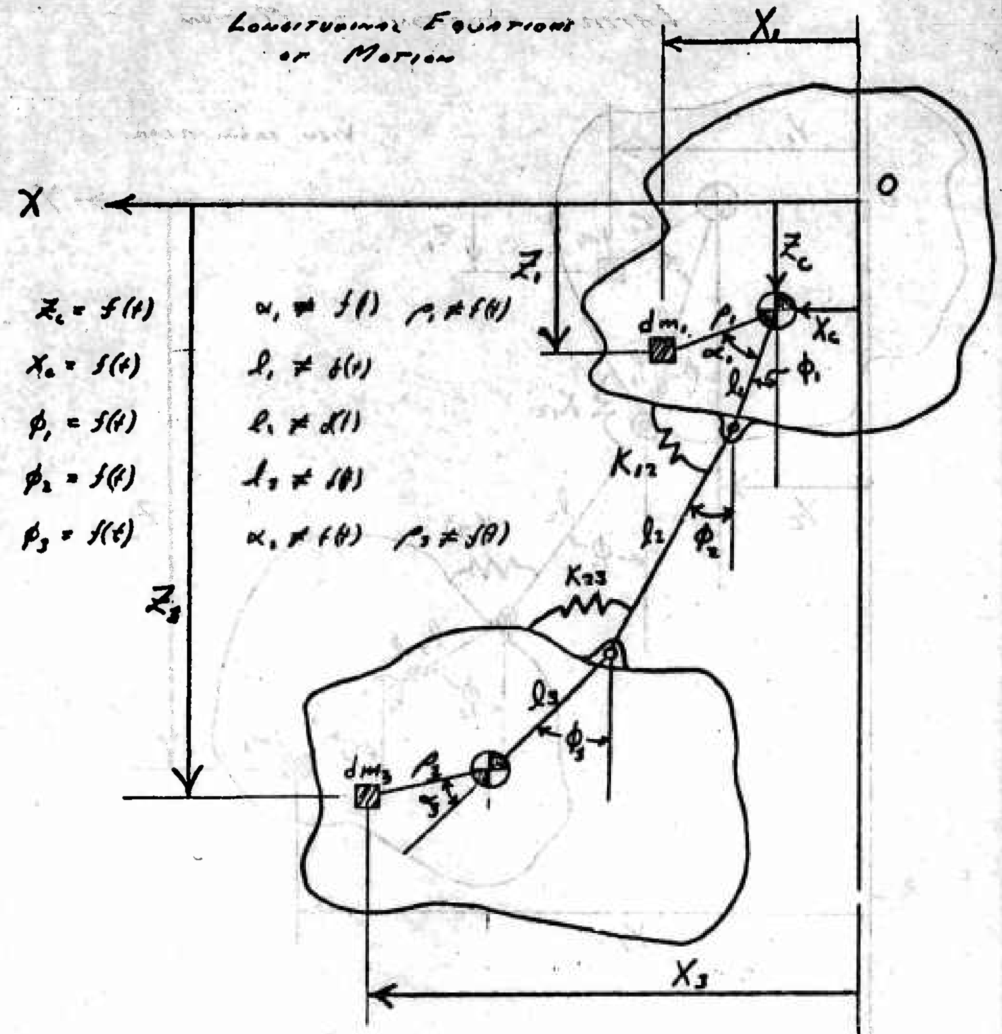
$\phi_2 = f(t)$ $\qquad$ $l_2 \neq f(t)$

$\phi_3 = f(t)$ $\quad$ $\psi_3 = f(t)$ $\qquad$ $l_3 \neq f(t)$

$\alpha_3 \neq f(t)$ $\quad$ $\rho_3 \neq f(t)$

AIRCRAFT RECOVERY

LONGITUDINAL EQUATIONS OF MOTION



TOTAL KINETIC ENERGY

$$T = \frac{1}{2}\int (\dot{X}_1^2 + \dot{Z}_1^2)\, dm_1 + \frac{1}{2}\int (\dot{X}_3^2 + \dot{Z}_3^2)\, dm_3$$

POTENTIAL ENERGY

$$V = g\int (\rho_1 \cos[\alpha_1 + \phi_1] - Z_1)\, dm_1 + g\int (l_1 + l_2 + l_3 + \rho_3 \cos(\alpha_3 + \phi_3) - Z_3)\, dm_3 + \frac{1}{2} K_{12} (\phi_1 - \phi_2) + \frac{1}{2} K_{23} (\phi_2 - \phi_3)$$

SUMMARY

This report presents results of a program of historical record surveys, analytic studies, and preliminary design pertaining to development of an aerial aircraft recovery and evacuation system for the United States Army. The work was performed by Vertol Division of Boeing Airplane Company under USATRECOM Contract DA44-177-TC-662.

Historical records examined include technical reports and correspondence of the U. S. Army as well as Engineering memoranda and Service Department reports of Vertol Division Boeing.

Aerial recovery operations have been performed at least fifty times, including tests and actual field missions. Pertinent data are not available in statistical quantities. However, the historical evidence supports a general conclusion that improving equipment and techniques for aerial aircraft recovery will serve a present and future mission requirement of the U. S. Army.

A fundamental step in the development of an optimized aerial aircraft recovery system is accomplished in the analytic studies reported herein. Mathematical predictions of the flight behavior of various prime mover helicopters coupled with disabled aircraft "loads" have been obtained by means of analog computer solutions of the equations of motion. The solutions encompass H-21 and H-34 prime movers, respectively, coupled with L-19, HU-1A, H-21, and H-34 aircraft suspended as external loads (the last three stripped to weigh approximately 3500 pounds each). Restraint of the load has been varied in pitch, roll, and yaw planes. Effects of longitudinal and lateral control stick displacements, applied separately, have been observed. The envelope of cases studied is the minimum which provides an index of flight behavior of all practical combinations of U. S. Army aircraft employed as prime movers or as recoverable loads.

The stability and control problems of transporting a damaged aircraft suspended beneath a helicopter have been determined by these analytic studies. Moreover, the effectiveness of various types of equipment in dealing with these problems has been rigorously studied in terms of their mathematical analogies on the electronic computer. It is shown analytically that pitch and roll stability of an inherently unstable external load can be provided by a multiple cable suspension system deployed from the apex of the prime mover helicopter cargo sling.

A method for restraining yaw rotation of the load in hover or transition flight (due to prime mover rotor downwash swirl), as well as for counteracting load-yawing in forward flight (due to inherent directional instability), has been devised and analytically substantiated. This system maintains the safety advantage of single-point connection

between prime mover and load. Hover and low-speed flight (0-30 knots) rotation tendencies of the load are resisted by a mechanical spring, created by inserting cable-spreader torque plates in the prime mover cargo sling and in the load cable-suspension rig. (Spring components are shown in Drawing SK10910, Sheet 2, included in this report.) Directional stability of the load in forward flight (approximately 30-50 knots) is provided by aerodynamic forces on recovery-kit fins strapped to the recovered aircraft, when necessary to replace or supplement its normal yaw-stabilizing devices due to crash damage. It is proposed that recovery-kit fins for functional testing be of segmented panel, honeycomb core construction, as shown in Drawing SK10910, Sheet 3.

The preliminary design effort has been correlated with the historical record surveys and analytic studies. Due consideration is accorded the recovery kit concept proposed for development by the Nems Clarke Company under Contract DA 44-177-TC-576. Some components of that kit have been used as a basis for design of suspension system elements shown on Sheet 1 of Drawing SK10910 in this report. These components can be integrated with the special yaw restraint devices evolved in this study to form a kit adaptable to any type of Army aircraft recovery operation. In fact, the principles developed and implemented in the present study can be applied to any operation involving transport of external cargo by helicopter. Illustrations of the application of the SK10910 recovery kit to a significant spectrum of aircraft recovery operations are shown in Drawings SK10911 through SK10921 in this report.

A portion of the design effort has been devoted to logistic considerations in aircraft recovery operations. Proper recognition of these aspects is essential to formulating a practical and effective recovery system. A discussion is presented of crash damage assessment, crash site terrain problems, preparation of the damaged aircraft for airlift, and communications between air and ground crews. Among the equipment items and techniques suggested here are inflatable lifting bags for erecting the downed aircraft to facilitate hook-up, a crane hoist that can be strapped at optional positions on the recoverable fuselage for dismantling heavy components, a protective saddle mat for the downed aircraft to reduce damage risk during recovery handling operations, and infrared communications equipment for recovery crew personnel. (Applications are depicted in Drawings SK10447 and SK10452 in this report.)

It was originally planned to conduct wind tunnel model tests in this program. These tests were to have a specific objectives:

(1) determining whether prime mover - external load combinations

would be subject to aerodynamic interference effects in forward flight due to proximity of the bodies; and (2) determining yaw characteristics of recoverable aircraft in a range of yaw angles beyond that available on record as basic design data of the aircraft (i.e., exceeding $\pm 20^{\circ}$). However, the analytic studies have revealed that the practical range of cable lengths for connecting prime mover and load is great enough to preclude aerodynamic interference in forward flight. Furthermore, the studies have also shown that load rotation can readily be restricted to within $\pm 20^{\circ}$ of yaw, even allowing for sluggish piloting technique of the prime mover helicopter. Findings of the analytic studies have therefore obviated the need for any data that might reasonably be expected from wind tunnel testing of small-scale models.

It is concluded that further development of this aircraft recovery system should be pursued by detail design and fabrication of test components, followed by qualification testing in accordance with the proposed flight test program outlined in this report.

CONCLUSIONS

On the basis of results obtained in the historical data survey the following conclusions are drawn concerning U. S. Army aircraft recovery and evacuation by helicopter:

(1) There is a growing operational requirement for the capability of performing this mission as a routine procedure.

(2) Under favorable conditions, the aerial aircraft recovery mission can be efficiently performed within the present state of the art (where "favorable" implies a high proficiency level of flight and ground personnel, temperate climate, crash-site terrain negotiable on foot, and a "load" with inherent flight stability).

(3) A significant number of operations can be expected when the conditions for aerial recovery by present methods will be unfavorable to an extent that mission failure is probable.

(4) Improvement of equipment and/or techniques for recovery of disabled aircraft by helicopter would contribute measurably to fulfillment of a present and future U. S. Army mission requirement.

On the basis of results obtained in the analytic studies, the following conclusions are drawn:

(5) The analog computer program developed for this study provides a highly effective "working tool" for determining behavior of the prime mover-external load combinations in flight.

(6) This computer program, as applied in this study, depicts behavior of coupled prime mover-load combinations throughout the envelope of practical interest of "load" stability characteristics, load weights and center of gravity positions, types of cable suspension, and mission speeds.

(7) Results of computer studies markedly demonstrate the stabilizing effects of tail surfaces on the "load" (in forward flight) and of deployment of multiple suspension cables from the apex of the prime mover cargo sling (in both hover and forward flight).

(8) Computer studies further indicate that multiple cable suspension (Reference Figure 2) will adequately compensate low inherent pitch and roll stability of a damaged "load".

(9) However, a need is indicated for additional devices to provide directional restraint:

a. against "load" rotation due to rotor downwash swirl of the prime mover helicopter in hover and transition flight (up to 30 knots).

b. for yaw stability of a directionally unstable load in forward cruise flight (30 knots to 50 knots).

(10) A preliminary design solution for the problems mentioned in Item (9), above, is offered in the aeromechanical yaw restraint system proposed in this report and depicted in Drawing SK10910, Sheets 2 and 3, in this report.

(11) The formulation of an effective aircraft recovery system must be correlated with the practical problems of assessment of crash damage, terrain at the crash site, and preparation of the damaged aircraft for airlift and evacuation. (A presentation covering these aspects is included in this report, offering design concepts such as application of inflatable lifting bags, a "strap-on" crane hoist, and a protective saddle mat for the downed aircraft to minimize further damage during recovery operations).

(12) Further development of the aircraft recovery system can best be served by detail design and fabrication of test components and subsequent performance of ground and flight qualification tests.

RECOMMENDATIONS

The conclusions reached upon completion of this study program, and stated on the preceding pages, lead to the following recommendations:

(1) That a program be initiated for detail design of aircraft recovery system components in general accordance with Drawing SK10910, included in this report.

(2) That, upon approval of detail design drawings, a program be initiated for fabrication of at least one unit of each recovery system component needed to perform the proposed flight test program outlined in this report

(3) That, when recovery system test units are available, the proposed flight test program be conducted to evaluate the system concept.

INTRODUCTION

The analytic and design approach employed throughout this study is directed toward practical implementation of standard operating procedures for aerial aircraft recovery and evacuation. The primary objective is to develop a simple, efficient and adaptable recovery system compatible with the analytical solution of the dynamic problems. Although aircraft recoveries by helicopter have been performed in the past, these operations have met with varying degrees of success or, in some cases, complete failure. The historical review of aerial aircraft recovery operations in this report reveals that previous successes must be attributed to some extent to exceptional proficiency and/or other fortuitous circumstances. Some of the problems encountered have been due to unsuitable recovery equipment, as well as inadequate communication and signaling methods for flight and ground personnel.

It is apparent that at least three major areas should be studied in attempting to transform the aircraft recovery mission into a routine helicopter operation:

(1) Development of suitable equipment

(2) Standard preparation for complete recovery mission

(3) Determination of flight characteristics of the prime mover helicopter coupled with the external load.

In the Historical Data Review, Analysis of the Problem, and other topical sections immediately following, accomplishments of this work program in the major study areas enumerated above are presented in detail.

HISTORICAL REVIEW OF RECOVERY OPERATIONS AND EQUIPMENT USED

The following review of aerial aircraft recovery operations describes approximately fifty such operations performed from 1954 to the present. The list cannot be considered all-inclusive but does provide substantial coverage of "modern" (post-Korean War) operations of this type. Data have been obtained primarily from surveys of U. S. Army technical reports and correspondence, as well as Engineering memoranda and Service Department reports of Vertol Division Boeing.

Recovery operations are listed under two general categories:

(1) Test Recoveries and (2) Field Recoveries. Salient features of each operation are discussed (and also itemized briefly in a tabular summary) with particular attention to the problems encountered. An attempt has been made to present a faithful interpretation, in condensed form, of all the records surveyed. Finally, an appraisal is given of the sum and substance of information conveyed by the review. Presented in two parts, this appraisal consists of (1) "General Observations" and (2) a "Summary of Problems Encountered in Recovery Operations." It is intended that, together, these two items should provide an objective statement of the significant problems of aerial aircraft recovery operations on the basis of historical evidence.

HISTORICAL REVIEW OF RECOVERY OPERATIONS AND EQUIPMENT USED

TEST RECOVERIES

1. Date: 10 October 1956

Site: Fort Sill, Oklahoma

Service: U. S. Army

Recovery Helicopter: H-34

Recovered Helicopter/Aircraft: L-19

Equipment Used:

Recovery aircraft. Standard H-34 sling and hook assembly. Recovered aircraft (L-19) internal control locks and brakes.

Special Equipment:

Aerial tow bar and wing spoilers.

Disassembly of Recovered Aircraft: None.

Number of Tests:

8 with spoilers, 15 without.

Comments:

During one test severe turbulence caused the L-19 to pitch up such that the tow bar damaged the recovery aircraft. When the L-19 dropped, the force was sufficient to open the H-34 hook and release the L-19, severely damaging it. Airspeed at this time was 35-40 knots. When first airlifting this load, there was a tendency for it to yaw 90^{o} to either side. This swinging tendency was eliminated by reducing clearance between hook and lifting eye to 1/8" per side since the H-34 is equipped with nonswivelling cargo hook. A cable lifting assembly was used and later abandoned due to excessive twisting while hovering and lifting the L-19. When approaching the L-19 for the hookup, the pilot must be at approximately 50 ft altitude and 50 ft away in order to avoid overturning the L-19 with the downwash. After coming to a hover approximately 50 ft directly above the L-19, the ground signal man directed the pilot slowly down until the hookup could be made.

Comments (Continued)

Problems: (1) Lift due to pitch
(2) Load rotation
(3) Downwash overturning load

2. Date: 14 October 1958

Site: Fort Eustis, Virginia

Service: U. S. Army

Recovery Helicopters: H-21C Operational

Recovered Helicopter/Aircraft: H-21 Fuselage

Equipment Used:

Aircraft recovery harness placed on test fuselage, and standard cargo sling on recovery aircraft. Prior to hookup to recovery aircraft a mobile crane with dynamometer was used to test-lift the fuselage to check weight. During this lift, it was observed that the fuselage rode well.

Disassembly of Recovered Aircraft:

Complete stripping of all components and hardware including landing gear and vertical stabilizer.

Comments:

The fuselage was set up and two ground crew members climbed on top of it to perform the hookup operation. When the recovery helicopter was brought into position over the fuselage, the downwash caused the fuselage to roll over onto its side endangering the hookup crew. Several pieces of loose equipment were also blown about, presenting additional hazards to the ground crew.

The second hookup attempt was accomplished with the hookup crew standing on the ground. After the hookup personnel cleared the area, the recovery aircraft then lifted the fuselage approximately 3 ft when it was observed to rotate 90° so that its longitudinal axis was perpendicular to the longitud-

TEST RECOVERIES

Comments (Continued)

inal axis of the helicopter. The pilot dropped the fuselage at this point due to the download exceeding his lifting ability at the normal engine rating. Since the lift capabilities of the H-21C exceeded the load by approximately 700 lb, it was concluded that the rotor downwash acting on the test fuselage contributed the excess download.

Problems: (1) Load rotation
(2) Hookup
(3) Hover downwash on rotated load

3. Date: 24 April 1959

Site: Fort Eustis, Virginia

Service: U. S. Army

EXTRACT FROM TEST 437 - AIRCRAFT RECOVERY AND EVACUATION SYSTEM. U. S. ARMY TRANSPORTATION RESEARCH AND ENGINEERING COMMAND

Equipment Used:

B. E. Wallace Products Corporation "Aircraft Universal Portable Hoist Equipment" under Contract DA44-177-TC582 to erect aircraft to a position suitable for hookup to recovery aircraft. A three-section spreader bar, capable of being assembled into six, twelve or eighteen foot lengths according to the length of the airframe component to be recovered. The spreader bar was suspended from the cargo hook of the recovery aircraft and a means was provided for adjusting the position of the suspension along the spreader bar to compensate for varying cg requirements. Four nylon web straps suspended the item to be recovered from the spreader bar. This equipment was tested using H-21 and H-34 helicopters as recovery vehicles.

Recovery Helicopter: H-21

Recovered Helicopter/Aircraft: H-13. 1150 lb gross weight

Disassembly of Recovered Aircraft: Not stated

Comments:

Four web straps were placed around fuselage attached to a two-section (12 ft) spreader bar. This aircraft was successfully recovered with no damage sustained by airframe or equipment. The load handled well in flight and 60 knots airspeed was attained.

Problems: No problems.

4. Recovered Helicopter/Aircraft: H-23. 1314 lb gross weight.

Disassembly of Recovered Aircraft: Not stated.

Comments:

Four web straps placed around fuselage and connected to two-section spreader bar (12 ft) sling by web strap cable assemblies. Takeoff and hover normal. Web strap slipped at the commencement of forward flight causing this lift to be terminated.

Problems: Unsuitable equipment.

5. Recovered Helicopter/Aircraft: L-19. Weight - 600 lb.

Disassembly of Recovered Aircraft:

Outer wing panels, engine, and vertical tail surface removed.

Comments:

Wing panels were attached to sides of L-19 fuselage. Four web straps encircled the fuselage and wings; these were connected to a two-section spreader bar (12 ft) by the web strap cable assembly. Hookup, takeoff and hover were accomplished without difficulty. Oscillation of load became evident as forward speed built up and at 40 knots, altitude 200 ft, these became so severe that the pilot jettisoned the load.

Problems: (1) Undesirable aerodynamics characteristics of load.

6. Recovered Helicopter/Aircraft: H-21 Fuselage

TEST RECOVERIES

Disassembly of Recovered Aircraft:

Complete strippage, gross weight 1800 lb.

Comments:

Four web straps encircled the fuselage and were attached to the three-section spread bar (18 ft) by the web strap cable assemblies.

The fuselage was initially propped up in an upright position but helicopter rotor downwash caused it to roll over. Subsequent attempts were made with the fuselage lying on its side. It was necessary for the recovery helicopter to approach either by flying up the longitudinal axis or by descending over the center of the fuselage to eliminate the rolling which resulted from the rotor downwash. The fuselage was eventually lifted to a hover but in the opinion of the pilot directional characteristics were such that forward flight was not achieved.

With this equipment the fuselage turned until its longitudinal axis was perpendicular to the longitudinal axis of the recovery helicopter. During one test when a wind of 15 knots was blowing, no tendency was exhibited for the fuselage to streamline. Stabilizing ropes from either end of the fuselage and held by crew members in the recovery aircraft were ineffective.

Problems: (1) Load rotation
(2) Undesirable forward flight directional characteristics of load
(3) Downwash before pickup

7. Recovered Helicopter/Aircraft: H-19

Disassembly of Recovered Aircraft:

Engine, transmission, rotor head and tail rotor removed. Gross weight remaining, 2700 lb.

Equipment Used:

Four web straps encircled fuselage and were attached to the

Equipment Used (Continued)

three-section spreader bar (18 ft) by web strap cable assemblies. The initial hookup was made with the spreader bar taped to the top of the H-19 fuselage to prevent rotor downwash from blowing the bar.

The hookup was then satisfactorily accomplished. During the lift, the sling cables damaged the oil cooler and pitot mast of H-19.

A second attempt was made with the spreader bar and sling thrown to one side after hookup. This method was successful with no fouling of the cables.

No difficulty was found during lift and hover but at slow forward speed the H-19 assumed a broadside position. The pilot then landed the load and a stabilizing rope was attached to the tail of the H-19 and held inside the H-21 by a crewman. This method being ineffective, the pilot then elected to attempt forward flight and after the fuselage oscillated during forward acceleration it stabilized 60° nose right at speeds 40 to 60 knots. Maximum speed attained was 60 knots and no control problems were encountered. Landing and release were accomplished without incident.

Problems: (1) Undesirable forward flight directional characteristics of load.

8. Recovery Helicopter: H-34

Recovered Helicopter/Aircraft: H-13

Disassembly of Recovered Aircraft:

Removal of rotor blades.

Equipment Used:

Sling and lifting eye attached to H-13 rotor mast. Because this point was not at the cg, the H-13 assumed a nose up attitude. Takeoff and hover was normal with the H-13 turning in the rotor downwash. Directional stability was poor but the pilot reported no control problems at speeds up to 80 kts.

TEST RECOVERIES

Problems: (1) Undesirable forward flight directional characteristics of load.
(2) Load rotation in hover.

9. Recovered Helicopter/Aircraft: H-21

Equipment Used:

Identical to that used when this airframe was lifted by H-21. Hookup, takeoff, and hover were accomplished without incident; however, the rotor downwash caused the fuselage to rotate. Since the H-34 does not have a swivelling cargo hook, the cables began to wind up; thus the attempt to transport the fuselage was abandoned.

Problems: (1) Load rotation in hover

10. Recovered Helicopter/Aircraft: H-19

Equipment Used:

Identical with that used when this airframe was lifted by H-21.

Hookup, takeoff and hover were accomplished without difficulty. The H-19 rotated in the rotor downwash during hover. The rotation stopped in forward flight at speeds up to 40 knots, with the airframe stabilizing at 80° nose right. When the speed exceeded 40 knots, the aircraft began to oscillate, causing difficulty in controlling the H-34. Landing was without incident.

When the recovery equipment was released from a position directly over the H-19 and at a height of approximately 10 feet, some damage was done to the airframe as a result of the equipment hitting it.

Problems; (1) Undesirable forward flight directional characteristics of the load.
(2) Load rotation in hover.

HISTORICAL REVIEW OF RECOVERY
OPERATIONS AND EQUIPMENT USED

FIELD RECOVERIES

1. Date: November 1954

Site: Fort Riley, Kansas

Service: U. S. Army

Recovery Helicopter: H-21C

Recovered Helicopter/Aircraft: L-19

Equipment Used:

Standard cargo sling on recovery aircraft. Attachment to recovered aircraft not available.

Disassembly of Recovered Aircraft: None

Comments:

No difficulties encountered up to 60 knots forward speed.

Problems: None

2. Date: 25 September 1955

Site: Tatalina, Alaska

Service: U. S. Air Force

Recovery Helicopter: H-21A

Recovered Helicopter/Aircraft: H-21A

Equipment Used:

The recovery aircraft was equipped with the standard H-21 cargo sling. The fuselage was lifted by cable slings coming to a common junction; a short length of cable led from the junction to the cargo sling on the recovery aircraft. Stabilizing rope, 1/2" diameter, later replaced by 3/4", was attached to the forward portion of recovered aircraft and leading into recovery aircraft through front door, then through a cargo tie-down ring in the floor. It finally was held by the crewman directing operations.

Disassembly of Recovered Aircraft:

The helicopter was stripped of equipment and components until it was down to a weight of approximately 2500 lb. Due to ice accumulation the actual weight lifted was approximately 3000 lb.

Comments:

For various reasons it was necessary to make four attempts before the fuselage was successfully lifted. The 1/2" diameter rope broke and was replaced by 3/4" diameter. It was found impossible for one man to direct the loading, also to hold the rope properly, so a second crewman was added. Airspeed was held to 40 knots since at a greater speed the stabilizing rope could not be held. Difficulty was encountered with ground crew-to-pilot signaling procedure.

Problems: Undesirable forward flight directional characteristics of load.

3. Date: 27 July 1956

Site: French North Africa

Service: French

Recovery Helicopter: H-21B

Recovered Helicopter/Aircraft: H-21B

Equipment Used:

Cargo sling. 3/8" stabilizing rope and cable. Sling size unknown.

Disassembly of Recovered Aircraft:

Fuselage completely stripped and split into two portions.

Comments:

A sling was made and attached to the fuselage sections, these being given sufficient room to oscillate if needed. Clear-

Comments (Continued):

ance between load and fuselage was 5-1/2 feet for aft section and 5 feet for forward section. The loads were attached to the recovery aircraft at their center of gravity.

No stabilizing rope was provided for the aft section through oversight, but at flight-speed of 50 knots it stabilized at 15° left yaw and only oscillated when affected by gusts or turbulence. No control difficulties. For the forward section the stabilizing rope was employed, and though it did not fail, it was subject to considerable chafing. 3/4" rope is recommended. During cruise the forward section was stable at 15° to 20° left yaw. After some mild turbulence the load swung right and stabilized with 10° right yaw.

Problems: Undesirable forward flight directional characteristics of load.

4. Date: 19 October 1956

Site: Willow, Alaska

Service: United States

Recovery Helicopter: H-21

Recovered Helicopter/Aircraft: L-20

Equipment Used:

Cargo sling on H-21. Method of attachment to L-20 not known.

Disassembly of Recovered Aircraft:

Stripping of wings.

Comments:

No details available as to difficulties encountered but recovery was successfully completed.

Problems: None

HISTORICAL REVIEW OF RECOVERY
OPERATIONS AND EQUIPMENT USED

FIELD RECOVERIES

5. Date: 7 May 1957

Site: Tsushima, Korea

Service: U.S.A.

Recovery Helicopter: H-21

Recovered Helicopter/Aircraft: L-19

Equipment Used:

One H-21 standard cargo sling. One L-19 special frame bolted to wing attachment fittings and attached to helicopter cargo sling.

Disassembly of Recovered Aircraft: Not stated.

Comments:

L-19 gross weight approximately 1700 lb. No difficulties in lifting the L-19 or controlling the helicopter during the flight were noted. Recovery successfully completed.

Problems: None

6. Date: 6 May 1958

Site: James River

Service: U.S.A.

Recovery Helicopter: H-21

Recovered Helicopter/Aircraft: H-23

Equipment Used:

Two standard H-13 rotor slings were wrapped around the main pitch bearing housings and attached to the H-21 cargo sling. Two stabilizing lines were attached to the H-23, one at each end of the airframe; these were led into the helicopter. One standard mechanic's tool box was also used.

HISTORICAL REVIEW OF RECOVERY OPERATIONS AND EQUIPMENT USED

FIELD RECOVERIES

Tools Used:

Stock No.	Description	Quantity
41-A-20-200	Adapter, Socket Wrench, 3/8 Male Sq. Plug, 1/2 Female Sq. Socket	1
41-H-485-300	Hammer, Inserted Face Plastic 1" Head Dia.	1
41-P-1714	Pliers, Diagonal Cutting	1
41-W-619-800	Wrench, Box 3/8 x 7/16	1
41-W-619-629	Wrench, Box 5/8 x 11/16	1
41-W-2999-75	Wrench, Socket 3/8 Sq. Drive 12 Point, 5/8 Opening	1
	Wrench Socket 1/2 Sq. Drive 1-1/8 Opening	1
8220-92012	Sling, Hoisting, Helicopter (H-13) Complete for Main Rotor	2

Disassembly of Recovered Aircraft:

Removal of main rotor blades.

Comments:

In this case, due to difficult swampy terrain, the recovery aircraft could not land to unload tools and ground crew and it was difficult to throw the stabilizing lines into the helicopter without danger of the lines fouling the rotating rotor blades. It is not stated in the report whether the stabilizing lines were held by crewmen or attached to the aircraft structure.

Trouble was encountered through lack of adequate ground-to-pilot signal procedure, both on hook-up and release. This resulted in the pilot entering the transition flight regime under the misconception that the hook-up to the load had not been accomplished.

Problems: (1) Undesirable forward directional characteristics of load.

(2) Communication.

7. Date: 20 December 1958

Site: Korea

Service: U.S.A.

Recovery Helicopter: H-21C

Recovered Helicopter/Aircraft: H-21C

Equipment Used: Cargo sling.

Disassembly of Recovered Aircraft: Complete stripping.

Comments:

Aircraft had frozen into the ground and had to be snatch lifted. The fuselage took up a nose-down attitude and tail swung 30°, striking the right vertical fin of the recovery aircraft. During the flight the fuselage swung even more and oscillated sufficiently to do further minor damage to the recovery aircraft. It was necessary to refuel during this flight. Landing and takeoff were completed without difficulty.

Recovery was successfully completed.

Problems: (1) Aerodynamic instability of load in forward flight.

(2) Preparation of load.

8. Date: 27 March 1960

Site: Newburgh, New York

Service: U. S. Air Force

Recovery Helicopter: H-37

FIELD RECOVERIES

Recovered Helicopter/Aircraft: H-21C

Equipment Used:

A mobile crane was used to establish the fuselage cg. The helicopter hoisting sling was unsatisfactory for lifting the H-21 and an additional 3/4" cable was used to provide adjustment until the H-21 was lifted in the normal flight attitude.

Disassembly of Recovered Aircraft:

Rotor, blades and hubs, forward and aft transmissions, radio equipment, inverters, engine, horizontal and vertical stabilizers, cabin and rescue doors, instruments, battery, engine drive shaft and fire curtain. Estimated gross weight 5500 lb.

Comments:

Static electricity must be grounded. Pilot to ground crew communication must be excellent. The recovered aircraft main gear oleo locks should be used to give the pilot a reliable indication that he has placed the load on the ground.

The nose wheel should be free to swivel. This gives the helicopter a pivot point in case of cross winds which tend to tip the load over due to hovering difficulties.

Problems: (1) Communication
(2) Static electricity
(3) Main eleos not locked
(4) Locked nose wheel

9. Date: 5 May 1960

Site: Not stated.

Service: U.S.A.

Recovery Helicopter: H-21C

Recovered Helicopter/Aircraft: L-19 Type Aircraft

HISTORICAL REVIEW OF RECOVERY
OPERATIONS AND EQUIPMENT USED

FIELD RECOVERIES

Equipment Used:

Spoilers on recovered aircraft (2 x 4 boards, tied spanwise over the forward wing spar), standard sling on recovery aircraft.

Disassembly of Recovered Aircraft: None

Comments:

Airspeed at cruise varied, depending on turbulence encountered. During hover, the downwash tended to pick up the aircraft and in effect vary the load weight. This required maximum displacement of cyclic pitch.

Weight of aircraft estimated at 2500 pounds. Stability was excellent except when turbulence was encountered. Sling was rigged to carry Cessna at slightly negative angle relative to H-21. This created heavy drag at higher forward speeds but held Cessna in place well. Maximum safe speed was 60 knots.

Problems: (1) Lift developed by the load.

SUMMARY OF AIRCRAFT RECOVERY OPERATIONS BY HELICOPTER

MISSION TYPE*	DATE	PLACE	SERVICE	RECOVERY HELICOPTER	RECOVERED AIRCRAFT TYPE	RECOVERED AIRCRAFT WEIGHT	PROBLEMS
Field (1)	Nov. 1954	Ft. Riley, Kansas	USA	H-21C	L-19	•	None Recorded
Field (2)	25 Sept.1955	Tatalina, Alaska	USAF	H-21A	H-21A	2,500 lb 3,000 lb	1. Directional Stability
Field (3)	27 July 1956	Algeria, N.Africa	French	H-21	H-21B		1. Directional Stability
Test (1)	10 Oct. 1956	Fort Sill, Okla.	USA	H-34	L-19 (23 Times)	1,700 lb	1. Lift Developed 2. Load Rotation 3. Downwash Over-turning Moment
Field (4)	19 Oct. 1956	Willow, Alaska		H-21	L-20		None Recorded
Field (5)	7 May 1957	Tsushima, Korea	USA	H-21	L-19	1,700 lb	None Recorded
Field (6)	6 May 1958	James River	USA	H-21	H-23		1. Directional Stability 2. Communication
Field (7)	20 Dec. 1958	Korea	USA	H-21C	H-21C		1. Pitch Instability of Load 2. Preparation of Load for Pick-Up
Test (2)	14 Oct. 1958	N.A.	USA	H-21C	H-21		1. Load Rotation 2. Hook-Up 3. Download
Test (3)	April 1959	Ft. Eustis, Va.	USA	H-21C	H-13	1,150 lb	Successful Recovery (Test)

RECORD OF AIRCRAFT OPERATIONS BY HELICOPTER (Continued)

MISSION TYPE*	DATE	PLACE	SERVICE	RECOVERY HELICOPTER	RECOVERED AIRCRAFT TYPE	RECOVERED AIRCRAFT WEIGHT	PROBLEMS
Test (4)	April 1959	Ft. Eustis, Va.	USA	H-21C	H-23	1,314 lb	1. Unsuitable Equipment
Test (5)	April 1959	Ft. Eustis, Va.	USA	H-21C	L-19	600 lb	1. Forward Flight Aerodynamic Instability
Test (6)	April 1959	Ft. Eustis, Va.	USA	H-21C	H-21	1,800 lb	1. Load Rotation 2. Directional Stability 3. Downwash
Test (7)	April 1959	Ft. Eustis, Va.	USA	H-21C	H-19	2,700 lb	1. Directional Stability
Test (8)	April 1959	Ft. Eustis, Va.	USA	H-34A	H-13	1,150 lb	1. Directional Stability 2. Load Rotation
Test (9)	April 1959	Ft. Eustis, Va.	USA	H-34A	H-21	1,800 lb	1. Load Rotation
Test (10)	April 1959	Ft. Eustis, Va.	USA	H-34A	H-19	2,700 lb	1. Directional Stability 2. Load Rotation
Field (8)	27 Mar 1960	Stewart AFB	USAF	H-37	H-21C	5,500 lb	1. Communication 2. Static Electricity 3. Oleos Not Locked 4. Locked Nose Wheel
Field (9)	5 May 1960	N.A.	USA	H-21C	L-19 Type Aircraft	2,500 lb	1. Lift Developed

*NOTE: The above recovery operations are described in more detail in the Historical Review preceding this tabular summary. The location of detail comments on each operation is indicated under the "Mission Type" column by reference to number sequence of the narrative accounts.

The following accounts contain all information obtained on the indicated recovery incidents:

DATE	PLACE	SERVICE	RECOVERY HELICOPTER	RECOVERED AIRCRAFT	DISASSEMBLY
22 Oct. 1958	Fort Sill, Okla.	USA	H-37	U-1A(Otter)	Wings, propeller, vertical and horizontal tail removed
-	-	-	H-37	L-23	Outer wing panels removed
-	-	USA	H-37 Crane	H-34	Rotor Blades
25 Sept.1956	N. A.	USA	H-21	H-23	Rotors Removed
8 June 1957	Ottawa, Canada	RCAF	H-21	Chipmunk	

HISTORICAL REVIEW OF RECOVERY OPERATIONS AND EQUIPMENT USED

GENERAL OBSERVATIONS

Hazards to Ground Operating Crew

1. Static electrical discharge through helicopter pickup hook (TRECOM 9R87-14-007-04 Test 481. 18 February 1960).

   (a) Static electricity produced from the pickup hooks of H-21C, H-34A and H-37A was found to be severe and unpredictable both in regard to polarity and intensity.

   (b) If static electricity is not previously discharged, operating personnel receiving an unexpected shock may inadvertently retreat into the tail rotor of any single rotor recovery helicopter.

   (c) The static electricity may discharge in the form of sparks which in turn can cause spilled gasoline and inflammable material to ignite or cause the detonation of electrically actuated ordnance items and rockets.

   (d) The static electricity should be discharged from the helicopter pickup hook to the earth by some form of static discharge probe before any operations are commenced. Operating personnel should also wear heavy rubber gloves to prevent personal injury or shock.

2. Helicopter rotor downwash.

   (a) Permanent injury to lungs, eyes and ears has been caused by sand, dust and flying debris generated by rotor downwash.

3. Objects falling from recovery helicopter.

   (a) Objects have also been observed to fall from the recovery helicopter endangering the members of the ground operating crew while working in the vicinity of the airborne helicopter.

   (b) To provide the necessary degree of protection, certain commanders have recommended that all ground personnel should be required to wear the U.S. Army steel service helmet, the U.S. Army gas mask and some approved form of ear plug or ear protector.

HISTORICAL REVIEW OF RECOVERY OPERATIONS AND EQUIPMENT USED

GENERAL OBSERVATIONS

4. In many reports commanders have felt that the development of a cargo hook capable of being operated from within the fuselage would relieve many of the problems stated in previous paragraphs.

Signaling and Communication

It is noted, in many of the reports of aircraft recovery operations, that one of the main difficulties in performing a successful recovery is pilot-to-ground crew signaling procedure.

When a microphone is used by the ground crewman directing a pilot, his speech is garbled by the aircraft noise, making it extremely difficult for the pilot to understand the instructions. At present there is apparently no adequate system of hand signals established since there is no mention of this in any of the surveyed reports.

Recovery Characteristics

From a study of the historical data collected, it can be seen that aerial recovery of L-19 aircraft does not present any difficulty in normal weather conditions. This aircraft has been lifted many times, and only two cases of difficulty, resulting in the loss of the aircraft, have been recorded. The recovery of the H-21 airframe has been accomplished several times, with difficulties encountered. The difficulties with the H-21 appear to be less when experienced pilots are operating the recovery helicopter. In some cases, a flight crewman has been exposed to danger when holding a stabilizing rope attached to one end of the recovered H-21 fuselage. The H-13 and H-23 series aircraft do not appear to present any appreciable difficulties regardless of the prime mover.

HISTORICAL REVIEW OF RECOVERY OPERATIONS AND EQUIPMENT USED

SUMMARY OF PROBLEMS ENCOUNTERED IN TEST AND FIELD OPERATIONS

Problems that result in mission failures are related primarily to the inflight characteristics of the load. These problems can be divided into two areas of consideration:

(1) Load rotation in hover; and

(2) Load instability in forward flight.

Problems encountered during hookup operations have not, in the past, resulted in mission failures. However, it is conceivable that future operations could be jeopardized by any one or a combination of these subsidiary problems. During the hookup, typical problems encountered have been:

(1) Static electricity discharge.

(2) Blowing sand, dirt and debris induced by rotor downwash.

(3) Rotor downwash forces that can result in overturning the downed aircraft.

(4) Inadequate communication between the pilot and the ground crew during the hookup operation was encountered several times, and one recovery operation was seriously jeopardized by misinterpretation of hand signals given by a ground crewman.

(5) Nearly all other problems can be placed in the general category of equipment deficiencies.

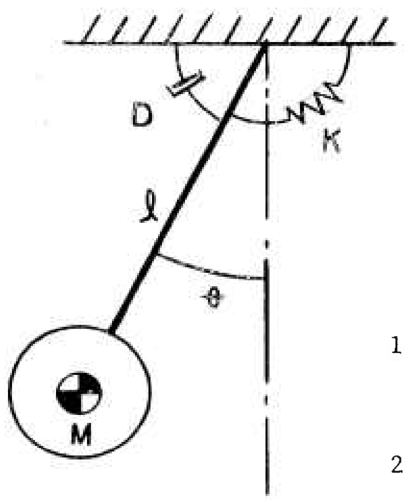
ANALYSIS OF THE PROBLEM

Equations of Motion of the Aerial Recovery of Disabled Aircraft

A major portion of the analytical effort was expended on the derivation and study of the equations of motion. The equations of motion divide into two problem areas: (1) The longitudinal equations of motion, and (2) the lateral equations of motion. The assumption is made that there are no couplings between the longitudinal and lateral modes; therefore, they are studied independently.

Derivation of the equations of motion was accomplished by the method of Lagrange. The Lagrange equations, which can be derived from the principle of virtual displacement, are amenable to the standard aerodynamic technique of applying small perturbations to a trimmed flight condition. An important limitation to this method of study is that the small perturbations are defined as, and limited to, small displacements that are compatible with the constraints of the steady state system. However, the range of applicability is adequate to define the helicopter response to stick motion within the regime of practical interest.

The problem of a helicopter carrying an external load is essentially the classical compound pendulum problem with aerodynamic and rotor forces acting as springs, dampers and forcing functions. A significant difference is the necessity to account for the moment of inertia of the load about its center of gravity. This inertia is usually considered small in comparison to the mass transfer term and is often neglected in the simple pendulum problem. (See Figure 1)



Icg = Moment of inertia about center of gravity

M = Mass

D = Pounds sec/rad

K = Pounds/rad

Equations of Motion

1) For $Icg \ll MI^2$

$$MI^2 \ddot{\theta} + glM \sin\theta + D\dot{\theta} + K\theta = 0$$

2) For $Icg \approx MI^2$

$$(Icg + MI^2)\ddot{\theta} + glM \sin\theta + D\dot{\theta} + K\theta = 0$$

FIGURE 1 - CLASSICAL PENDULUM PROBLEM

The problem becomes more complex as more degrees of freedom are introduced. The aircraft recovery analysis incorporates five (5) degrees of freedom in the longitudinal study and six (6) degrees of freedom in the lateral study. The complete derivation of the equations of motion is contained in Appendix 1, Volume II. The equations were derived in general form to permit study of a broad range of configurations of the aircraft recovery system. Tables I and II summarize the longitudinal and lateral equations of motion.

Two methods of suspending the loads were considered in the Phase I study. In this report they will be referred to as the single-cable suspension and the double-cable suspension. Figure 2 depicts the basic geometry of the two systems.

Inputs to the equations of motion are calculated from the physical characteristics of each coupled system and the aerodynamic forces developed by the rotors, fuselage of the prime mover and the external load. The characteristics of loads used in the first part of the investigation are listed in Table III. These characteristics are for the undamaged aircraft (effects of aerodynamic damage are studied later). This information was furnished by manufacturers of the respective aircraft.

The aerodynamic characteristics of the prime movers are summarized in Tables IV and V. These data are for the most part calculated by Vertol IBM Digital Computer Programs and are functions of the physical parameters of the prime movers. The prime mover parameters used as inputs to the Digital Programs are listed in Table VI. The Digital Programs used are quite complex, but a detailed discussion of the derivations would not enhance the clarity of this analysis. However, it is pertinent to offer a brief discussion showing the applicability of these Digital Programs to the present investigation.

Longitudinal Trim Analyses and Power Calculation - Vertol IBM Program No. 1226 (Ref. 1)

This program determines the control positions and fuselage attitude necessary for equilibrium (trim) at any chosen combination of helicopter geometry, weight, center of gravity, altitude and airspeed. Additional outputs include such items as blade flapping, coning, and power required. Because the longitudinal trim equations are nonlinear, the solution is carried out iteratively. The treatment of the problem is detailed, and in most cases, small angle assumptions are avoided. The results of this analysis have been successfully correlated with flight test data from the Boeing-Vertol H-21, Model 44, Model 107 Prototype and YHC-1A. The analysis was primarily designed for tandem rotor applications. For purposes of this study, the program was modified to permit analysis of single rotor type prime movers.

FIGURE 2
AIRCRAFT RECOVERY CABLE

SUSPENSION GEOMETRY

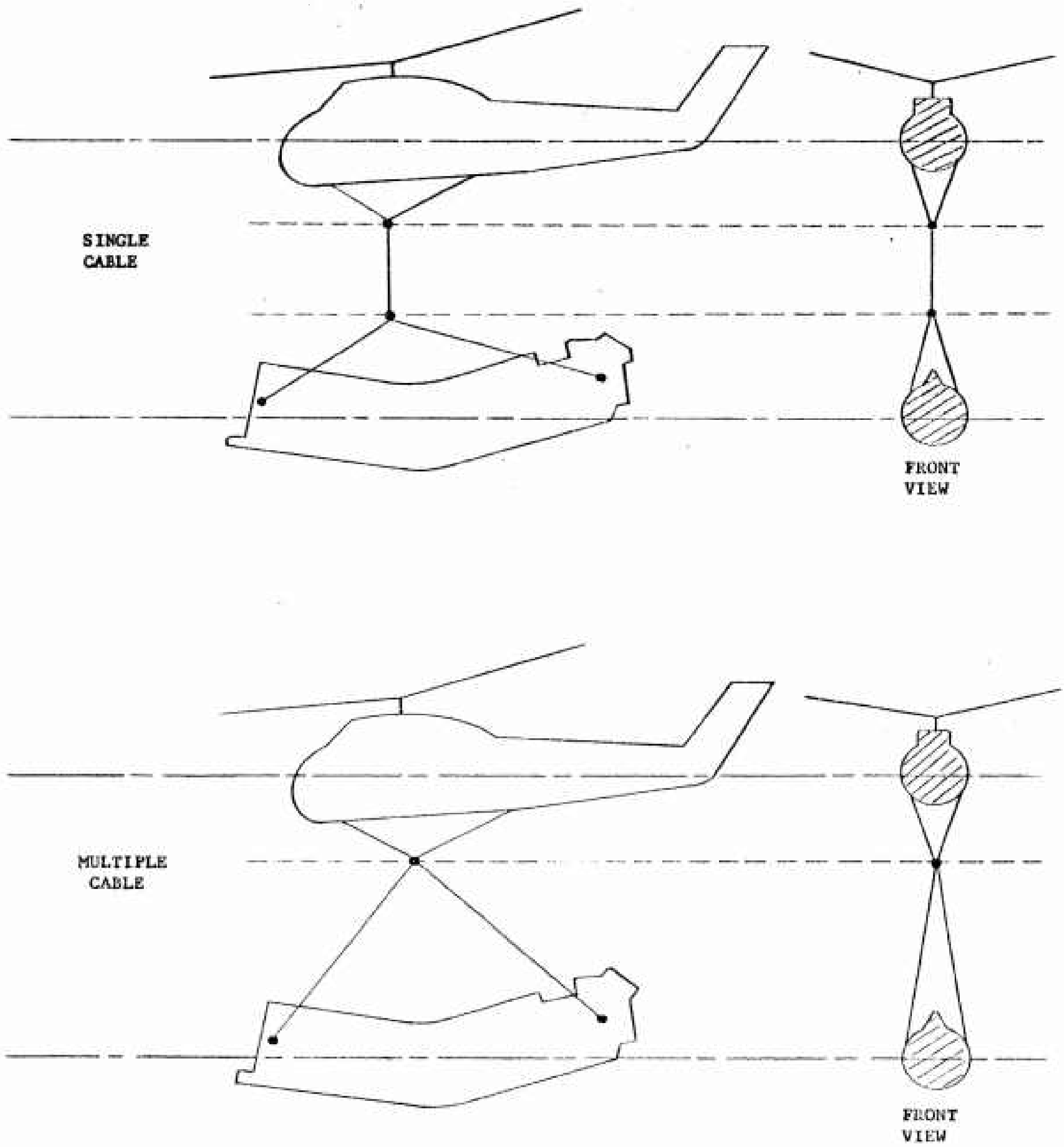


TABLE I SUMMARY OF LONGITUDINAL EQUATIONS OF MOTION.

i	$\ddot X_c = \sum_0^n A_i$		$\ddot Z_c = \sum_0^n B_i$		$\ddot\phi_1 = \sum_0^n C_i$		$\ddot\phi_2 = \sum_0^n D_i$		$\ddot\phi_3 = \sum_0^n E_i$		$\dot X_3 = \sum_0^n F_i$	
1	$\frac{M_3 l_1 \cos\gamma_1}{M_1+M_3}$	$-\ddot\phi_1$	$\frac{M_3 l_1 \sin\gamma_1}{M_1+M_3}$	$-\ddot\phi_1$	$\frac{M_3 l_1 l_2 \cos(\gamma_1-\gamma_2)}{I_1+M_3 l_1^2}$	$-\ddot\phi_2$	$\frac{M_3 l_1 l_2 \cos(\gamma_1-\gamma_2)}{M_3 l_2^2}$	$-\ddot\phi_1$	$\frac{M_3 l_1 l_3 \cos(\gamma_1-\gamma_3)}{I_3+M_3 l_3^2}$	$-\ddot\phi_1$	1	$\dot X_c$
2	$\frac{M_3 l_2 \cos\gamma_2}{M_1+M_3}$	$-\ddot\phi_2$	$\frac{M_3 l_2 \sin\gamma_2}{M_1+M_3}$	$-\ddot\phi_2$	$\frac{M_3 l_1 l_3 \cos(\gamma_1-\gamma_3)}{I_1+M_3 l_1^2}$	$-\ddot\phi_3$	$\frac{M_3 l_2 l_3 \cos(\gamma_2-\gamma_3)}{M_3 l_2^2}$	$-\ddot\phi_3$	$\frac{M_3 l_2 l_3 \cos(\gamma_2-\gamma_3)}{I_3+M_3 l_3^2}$	$-\ddot\phi_2$	$l_1\cos\gamma_1$	$\dot\phi_1$
3	$\frac{M_3 l_3 \cos\gamma_3}{M_1+M_3}$	$-\ddot\phi_3$	$\frac{M_3 l_3 \sin\gamma_3}{M_1+M_3}$	$-\ddot\phi_3$	$\frac{M_3 l_1 \cos\gamma_1}{I_1+M_3 l_1^2}$	$-\ddot X_c$	$\frac{M_3 l_2 \cos\gamma_2}{M_3 l_2^2}$	$-\ddot X_c$	$\frac{M_3 l_3 \cos\gamma_3}{I_3+M_3 l_3^2}$	$-\ddot X_c$	$l_2\cos\gamma_2$	$\dot\phi_2$
4	$\frac{X_\theta + X_\alpha}{M_1+M_3}$	ϕ_1	$\frac{Z_u}{M_1+M_3}$	$\dot X_c$	$\frac{M_3 l_1 \sin\gamma_1}{I_1+M_3 l_1^2}$	$-\ddot Z_c$	$\frac{M_3 l_2 \sin\gamma_2}{M_3 l_2^2}$	$-\ddot Z_c$	$\frac{M_3 l_3 \sin\gamma_3}{I_3+M_3 l_3^2}$	$-\ddot Z_c$	$l_3\cos\gamma_3$	$\dot\phi_3$
5	$\frac{X_u}{M_1+M_3}$	$\dot X_c$	$\frac{Z_\alpha}{M_1+M_3}$	ϕ_1	$\frac{-M_3 g l_1 \cos\gamma_1 + M_{\alpha_1}}{I_1+M_3 l_1^2}$	ϕ_1	$\frac{M_3 g l_2 \cos\gamma_2}{M_3 l_2^2}$	$-\phi_2$				
6	$\frac{X_{\dot\alpha}/U_0}{M_1+M_3}$	$\dot Z_c$	$\frac{Z_{\dot\alpha}/U_0}{M_1+M_3}$	$\dot Z_c$					$\frac{g\frac{\partial Y_3}{\partial\alpha_3}\left[l_3\sin\gamma_3 \text{[illegible]}\right] - M_3 g l_3\cos\gamma_3 + g\frac{\partial \text{[illegible]}}{\partial\alpha_3}}{I_3+M_3 l_3^2}$	ϕ_3		
7	$\frac{X_{\delta_c}}{M_1+M_3}$	δ_c	$\frac{Z_{\dot\theta}}{M_1+M_3}$	$\dot\phi_1$	$\frac{M_u}{I_1+M_3 l_1^2}$	$\dot X_c$	$\frac{g\frac{\partial Y_3}{\partial\alpha_3}\left[l_2\sin\gamma_2\right]}{M_3 l_2^2}$	ϕ_3	$\frac{U_0\rho f_3\left[l_3\sin\gamma_3\right]}{I_3+M_3 l_3^2}$	$\dot X_3$	$\dot Z_3 =$	
8	$\frac{X_{\theta_c}}{M_1+M_3}$	θ_c	$\frac{Z_{\delta_c}}{M_1+M_3}$	δ_c	$\frac{M_{\dot\alpha}/U_0}{I_1+M_3 l_1^2}$	$\dot Z_c$	$\frac{-\rho f_3 U_0\left[l_2\sin\gamma_2\right]}{M_3 l_2^2}$	$\dot X_3$	$\frac{\frac{g}{U_0}\left[\frac{\partial Y_3}{\partial\alpha_3}+(l_3\sin\gamma_3)\frac{\partial Y_3}{\partial\alpha_3}\right]}{I_3+M_3 l_3^2}$	$\dot Z_3$	$\sum_0^n G_i$ 1) 1	$\dot Z_c$
9	$\frac{X_{\dot\theta}}{M_1+M_3}$	$\dot\phi_1$	$\frac{Z_{\theta_c}}{M_1+M_3}$	θ_c	$\frac{M_{\dot\theta}}{I_1+M_3 l_1^2}$	$\dot\phi_1$	$\frac{\frac{1}{U_0}\frac{\partial Y_3}{\partial\alpha_3}\left[l_2\sin\gamma_2\right]}{M_3 l_2^2}$	$\dot Z_3$			2) $l_1\sin\gamma_1$	$\dot\phi_1$
10	$\frac{\rho U_0 f_3}{M_1+M_3}$	$-\dot X_3$	$\frac{g\frac{\partial Y_3}{\partial\alpha_3}}{M_1+M_3}$	$-\phi_3$	$\frac{\frac{g}{U_0} l_1\sin\gamma_1}{I_1+M_3 l_1^2}$	$\dot Z_3$					3) $l_2\sin\gamma_2$	$\dot\phi_2$
11					$\frac{-\rho U_0 f_3 l_1\cos\gamma_1}{I_1+M_3 l_1^2}$	$\dot X_3$					4) $l_3\sin\gamma_3$	$\dot\phi_3$
12			$\frac{\frac{g}{U_0}\frac{\partial Y_3}{\partial\alpha_3}}{M_1+M_3}$	$-\dot Z_3$	$\frac{M_{\delta_c}}{I_1+M_3 l_1^2}$	δ_c						
13					$\frac{M_{\theta_c}}{I_1+M_3 l_1^2}$	θ_c						
14					$\frac{g\frac{\partial Y_3}{\partial\alpha_3} l_1\sin\gamma_1}{I_1+M_3 l_1^2}$	ϕ_3						

TABLE II SUMMARY OF LATERAL EQUATIONS OF MOTION

i	$\ddot{Y}_c = \sum_0^n A_i$		$\ddot{\phi}_1 = \sum_0^n B_i$		$\ddot{\phi}_2 = \sum_0^n C_i$		$\ddot{\phi}_3 = \sum_0^n D_i$		$\ddot{\psi}_1 = \sum_0^n E_i$		$\ddot{\psi}_3 = \sum_0^n F_i$		$\dot{Y}_3 = \sum_0^n G_i$		$\beta = H + J$	
1	$\frac{-M_3 l_1}{M_1+M_3}$	$\ddot{\phi}_1$	$\frac{-M_3 l_1 l_2}{I_{x_1}+M_3 l_1^2}$	$\ddot{\phi}_2$	$\frac{-M_3 l_1 l_2}{M_3 l_2^2}$	$\ddot{\phi}_1$	$\frac{-M_3 l_1 l_3}{I_{x_3}+M_3 l_3^2}$	$\ddot{\phi}_1$	$\frac{U_{zx_1}-M_3 d l_1}{I_{z_1}+M_3 d^2}$	$\ddot{\phi}_1$	$\frac{U_{zx_3}}{I_{z_3}}$	$\ddot{\phi}_3$	1	$\dot{Y}_c$	$\beta_1 =$ $H_1 = \frac{1}{U_0}$	$\dot{Y}_c$
2	$\frac{-M_3 l_2}{M_1+M_3}$	$\ddot{\phi}_2$	$\frac{-M_3 l_1 l_3}{I_{x_1}+M_3 l_1^2}$	$\ddot{\phi}_3$	$\frac{-M_3 l_2 l_3}{M_3 l_2^2}$	$\ddot{\phi}_3$	$\frac{-M_3 l_2 l_3}{I_{x_3}+M_3 l_3^2}$	$\ddot{\phi}_2$	$\frac{-M_3 d l_2}{I_{z_1}+M_3 d^2}$	$\ddot{\phi}_2$	$\frac{K}{I_{z_3}}$	ψ_1	l_1	$\dot{\phi}_1$	$H_2 = -1$	ψ_1
3	$\frac{-M_3 l_3}{M_1+M_3}$	$\ddot{\phi}_3$	$\frac{U_{zx_1}-M_3 d l_1}{I_{x_1}+M_3 l_1^2}$	$\ddot{\psi}_1$	$\frac{-M_3 d l_2}{M_3 l_2^2}$	$\ddot{\psi}_1$	$\frac{-M_3 d l_3}{I_{x_3}+M_3 l_3^2}$	$\ddot{\psi}_1$	$\frac{-M_3 d l_3}{I_{z_1}+M_3 d^2}$	$\ddot{\phi}_3$	$\frac{-K}{I_{z_3}}$	ψ_3	l_2	$\dot{\phi}_2$	$\beta_3 =$ $J_1 = \frac{1}{U_0}$	$\dot{Y}_3$
4	$\frac{-M_3 d}{M_1+M_3}$	$\ddot{\psi}_1$	$\frac{-M_3 l_1}{I_{x_1}+M_3 l_1^2}$	$\ddot{Y}_c$	$\frac{-M_3 l_2}{M_3 l_2^2}$	$\ddot{Y}_c$	$\frac{U_{zx_3}}{I_{x_3}+M_3 l_3^2}$	$\ddot{\psi}_3$	$\frac{-M_3 d}{I_{z_1}+M_3 d^2}$	$\ddot{Y}_c$	$\frac{N_{\beta_3}}{I_{z_3}}$	β_3	l_3	$\dot{\phi}_3$	$J_2 = -1$	ψ_3
5	$\frac{Y_{\dot{\psi}}}{M_1+M_3}$	$\dot{\psi}_1$	$\frac{-L_{\dot{\psi}}}{I_{x_1}+M_3 l_1^2}$	$\dot{\psi}_1$	$\frac{-M_3 s l_2}{M_3 l_2^2}$	β_1	$\frac{-M_3 l_3}{I_{x_3}+M_3 l_3^2}$	$\ddot{Y}_c$	$\frac{-N_{\dot{\psi}}}{I_{z_1}+M_3 d^2}$	$\dot{\phi}_1$	$\frac{N_{\dot{\psi}_3}}{I_{z3}}$	$\dot{\psi}_3$	d	$\dot{\psi}_1$		
6	$\frac{+Y_{\dot{\phi}}}{M_1+M_3}$	$\dot{\phi}_1$	$\frac{+L_{\dot{\phi}}}{I_{x_1}+M_3 l_1^2}$	$\dot{\phi}_1$	$\frac{l_2 Y_{\beta_3}}{M_3 l_2^2}$	β_3	$\frac{-M_3 g l_3}{I_{x_3}+M_3 l_3^2}$	ϕ_3	$\frac{N_{\dot{\phi}}}{I_{z_1}+M_3 d^2}$	$\dot{\psi}_1$						
7	$\frac{Y_{\phi}}{M_1+M_3}$	β_1	$\frac{-M_3 g l_1}{I_{x_1}+M_3 l_1^2}$	ϕ_1			$\frac{L_{\beta_3}+l_3 Y_{\beta_3}}{I_{x_3}+M_3 l_3^2}$	β_3	$\frac{-K}{I_{z_1}+M_3 d^2}$	ψ_1						
8	$\frac{Y_{\beta_3}}{M_1+M_3}$	β_3	$\frac{-L_{\beta_1}}{I_{x_1}+M_3 l_1^2}$	β_1					$\frac{K}{I_{z_1}+M_3 d^2}$	ψ_3						
9	$\frac{Y_{\delta_1}}{M_1+M_3}$	δ_1	$\frac{-L_{\beta_3}}{I_{x_1}+M_3 l_1^2}$	β_3					$\frac{N_{\beta_1}}{I_{z_1}+M_3 d^2}$	β_1						
10	$\frac{Y_{\delta_R}}{M_1+M_3}$	δ_R	$\frac{-L_{\delta_1}}{I_{x_1}+M_3 l_1^2}$	δ_1					$\frac{Y_{\beta_3} d}{I_{z_1}+M_3 d^2}$	β_3						
11	$\frac{Y_{\phi}}{M_1+M_3}$	ϕ_1	$\frac{-L_{\delta_R}}{I_{x_1}+M_3 l_1^2}$	δ_R					$\frac{N_{\delta_1}}{I_{z_1}+M_3 d^2}$	δ_1						
12	$\frac{Y_w}{M_1+M_3}$	$\dot{Y}_c$	$\frac{-L_w}{I_{x_1}+M_3 l^2}$	$\dot{\chi}$					$\frac{N_{\delta_R}}{I_{z_1}+M_3 d^2}$	δ_R						
13																

TABLE III

DISABLED AIRCRAFT CHARACTERISTICS

(AERODYNAMIC CHARACTERISTICS ARE FOR UNDAMAGED AIRCRAFT)

Aircraft Type	I_{x_3} Slugs-ft^2	I_{z_3}	I_{y_3}	I_{xz_3}	Y_3 lbs/rad	N_3 ft.lbs/rad	L_3 ft.lbs/rad	L_3 lbs/rad	f_3 ft^2	M_3 ft.lbs/rad
H-21	2,000	30,000	30,000	0	-2,720	14,650	10,200	1,400	38	-12,000
H-34	1,300	6,000	7,000	0	-1,320	6,800	0	382	37	0
HU-1A	1,200	5,500	10,540	0	- 779	284	224	620	18	- 5,900
L-19	750	1,700	1,215	0	- 519	416	-737	6,500	8	- 2,940

I_{x_3} = Disabled Aircraft Moment of Inertia abcut the X Axis

I_{z_3} = Disabled Aircraft Moment of Inertia about the Z Axis

I_{y_3} = Disabled Aircraft Moment of Inertia about the Y Axis

I_{xz_3} = Disabled Aircraft Product Moment of Inertia

Y_{β_3} = Disabled Aircraft Partial Derivative of Side Force with Respect to Sideslip Angle

N_{β_3} = Disabled Aircraft Partial Derivative of Yaw Moment with Respect to Sideslip Angle

L_{β_3} = Disabled Aircraft Partial Derivative of Roll Moment with Respect to Sideslip Angle

M_{α_3} = Disabled Aircraft Partial Derivative of Pitch Moment with Respect to Angle or Attack

L_{α_3} = Disabled Aircraft Partial Derivative of Lift Force with Respect to Angle or Attack

f_3 = Disabled Aircraft Flat Plate Area (D/q)

TABLE IV

PRIME MOVER LONGITUDINAL STABILITY DERIVATIVES

	H-21					H-34	
	G.W.-10781 Basic 50 Knots f = 38	G.W.-12300 L-19 50 Knots f = 46	G.W.-14300 HU-1A 50 Knots f = 56	G.W.-14300 H-21 - H-34 50 Knots f = 75	G.W.-12500 Hover	G.W.-11500 50 Knots	G.W.-11500 Hover
Z_u	- 41	- 47	- 53.5	- 46	---	129	---
Z_α	- 21,354	- 21,340	- 21,657	- 21,850	---	- 23,800	---
$Z_{\dot\theta}$	- 1,384	- 1,410	- 1,307	- 1,275	---	---	---
Z_δ	- 134	- 137	- 157	- 120	---	- 720	---
Z_{θ_c}	- 92,330	- 92,306	- 93,745	- 94,286	---	---	---
X_u	- 12	- 15	- 19	- 22.5	- 10.5	- 9.2	- 7.6
X_α	256	+ 256	264	535	---	- 415	---
$X_{\dot\theta}$	438	+ 450	356	500	---	---	56.2
X_δ	- 9	- 414	- 471	- 471	---	- 344	---
X_{θ_c}	- 1,748	- 2,160	- 2,662	- 1,454	---	---	---
X_θ	- 10,781	- 12,300	- 14,300	- 14,300	---	---	---
M_u	- 98	- 180	- 253	- 257	720	230	84.9
M_α	52,079	52,630	47,719	42,264	---	- 7,890	---
$M_{\dot\theta}$	-154,295	-154,464	-153,111	-151,569	- 7,100	- 8,210	- 8,060
M_δ	20,212	20,346	20,254	19,988	- 19,400	3,940	4,160
M_{θ_c}	283,206	289,031	270,179	244,791	---	---	---

Z = Wind Axis Z Force (+ Down)
X = Wind Axis X Force (+ Forward)
M = Pitch Moment about the Y Axis (+ Nose Up)

Subscript Indicates Partial Derivative (e.g. $Z_u = \frac{\partial Z}{\partial u}$)

u = Velocity - fps
α = Angle of Attack - Radians
$\dot\theta$ = Pitch Rate - Radians/sec
δ = Longitudinal stick - inches
θ_c = Collective pitch - degrees
θ = Pitch Attitude of Prime Mover

TABLE V

PRIME MOVER LATERAL-DIRECTIONAL STABILITY DERIVATIVES

	G.W. 10781 (Basic) 50 Knots f = 38 ft^2	G.W. 12300 (L-19) 50 Knots f = 46	H-21 G.W. 14300 (HU1A) 50 Knots f = 56	G.W. 14300 (H-21)(H-34) 50 Knots f = 75	G.W. 12500 Hover	H-34 G.W. 11500 50 Knots	Hover
Y	- 2,943	- 3,466	- 5,376	- 5,685	---	- 4,928	---
Y	- 697	- 697	- 697	- 697	- 8.74	---	13.6
Y	- 578	- 699	- 860	- 880	- 637.5	---	562
Y	169	193	225	235	---	266	---
Y	5.7	7.8	10.5	12	---	---	---
N	16,634	13,223	12,311	11,100	---	54,500	---
N	- 9,440	- 9,440	- 9,440	- 9,440	---	18,000	---
N	113	146	186	195	---	---	---
N	610	697	813	850	---	---	---
[illegible]	- 21,826	- 22,818	- 24,448	25,200	---	- 11,790	---
L	- 2,338	- 6,048	- 6,867	- 7,000	- 79.7	---	- 102.2
L	- 6,797	- 6,335	- 7,052	- 7,100	- 6725	- 7,641	-8060
L	1,597	1,746	1,943	2,000	1451	4,100	3120
L	- 989	- 1,123	- 1,301	- 1,350	---	---	---
L	---	---	---	---	- 79.7	---	---

Y = Wind Axis Y Force (+ Right)
N = Yaw Moment About the Z Axis (+ Nose Right)
L = Roll Moment About the X Axis(+ Roll Right)

Subscript Indicates Partial Derivative (e.g. $Y_\beta = \frac{\partial Y}{\partial \beta}$)

β = Sideslip Angle - Radians
$\dot{\psi}$ = Yaw Rate - Radians/sec
$\dot{\phi}$ = Roll Rate - Radians/sec
δ_S = Lateral Stick - inches
δ_R = Pedal Displacement - inches
ω = Sideward Velocity - fps

TABLE VI SUMMARY OF PRIME MOVER PHYSICAL DATA

Section	Parameter	Unit	H-21 Min Fly Wt	H-21 Max Out G.E.	H-34 Min Fly Wt	H-34 Max Out G.E.	H-37 Min Fly Wt	H-37 Max Out G.E.
	GROSS WEIGHT		10,690 Incl. 1.5 Hr. Fuel	14,350 Std. SL	8,719 Incl. 1.5 Hr. Fuel	12,500 Std. SL	23,402 Incl. 1.5 Hr. Fuel	30,939 Std. SL
	Max Sling Load & Download		3,419		3,540		7,237	
	I_x		4,000	4,377	5,190	G.W. 13500 5,720		43,712
	I_y		82,300	89,235	25,405	28,100		95,892
	I_z		82,000	89,026	21,587	23,800		115,106
	I_{xz}			-633	0	NA		NA
KINEMATICS	Collective Lever Travel	In.	12.00		10.5			
KINEMATICS	Pitch .75R Blade Travel	Deg	1 - 17		1 - 12.5		1 - 12	
KINEMATICS – LONGITUDINAL CONTROL	Stick Travel	In.	±7.61		±7.0			
KINEMATICS – LONGITUDINAL CONTROL	DCP Blade Travel (stick)	Deg	±3.00					
KINEMATICS – LONGITUDINAL CONTROL	DCP Blade Travel "q" Sensor, Fwd	Deg						
KINEMATICS – LONGITUDINAL CONTROL	DCP Blade Travel "q" Sensor, Aft	Deg						
KINEMATICS – LONGITUDINAL CONTROL	CYC Blade Travel Stick	Deg	±6.00		±12.0		+12 - -14	
KINEMATICS – LONGITUDINAL CONTROL	CYC Blade Travel "q" Sensor, Fwd	Deg						
KINEMATICS – LONGITUDINAL CONTROL	CYC Blade Travel "q" Sensor, Aft	Deg						
KINEMATICS – LONGITUDINAL CONTROL	Rigged Long Dihedral, Fwd	Deg	+2.46					
KINEMATICS – LONGITUDINAL CONTROL	Rigged Long Dihedral, Aft	Deg	-2.46					
KINEMATICS – LONGITUDINAL CONTROL	Stick Positioner, Stick Range	Deg	±2.79					
KINEMATICS – LONGITUDINAL CONTROL	Stick Positioner, Blade Travel	Deg	±1.1					
KINEMATICS – LAT. CONTROL	Stick Travel	In.	±5.62		±7.0		±7.0	
KINEMATICS – LAT. CONTROL	Blade Travel, Fwd	Deg	±5.00		±9.0			
KINEMATICS – LAT. CONTROL	Blade Travel, Aft	Deg	±5.00		0			
KINEMATICS – DIR. CONTROL	Pedal Travel	In.	±3.25		±6.5		±3.25	
KINEMATICS – DIR. CONTROL	Blade Travel, Fwd	Deg	±5.00		30° - -20°, 6° neut.			
KINEMATICS – DIR. CONTROL	Blade Travel, Aft	Deg	±5.00		0			
KINEMATIC RATIOS	$\partial\theta_{1F}/\partial\delta_R$	Rad/In	-.02685		0		0	
KINEMATIC RATIOS	$\partial\theta_{1R}/\partial\delta_R$	Rad/In	-.02685					
KINEMATIC RATIOS	$\partial\theta_{1F}/\partial\delta_L$	Rad/In	-.01553		-.030		-.02235	
KINEMATIC RATIOS	$\partial\theta_{1R}/\partial\delta_L$	Rad/In	+.01553					
KINEMATIC RATIOS	$\partial\theta_{2F}/\partial\delta_L$	Rad/In	+.01376		+.030		+.0298	
KINEMATIC RATIOS	$\partial\theta_{2R}/\partial\delta_L$	Rad/In	+.01376					
KINEMATIC RATIOS	$\partial\theta_{0F}/\partial\delta_c$	Rad/In	+.00688		0		0	
KINEMATIC RATIOS	$\partial\theta_{0R}/\partial\delta_c$	Rad/In	-.00688					
PHYSICAL DATA	a	1/Rad	5.73		5.73		5.73	
PHYSICAL DATA	e	Ft	.3833333		1.0		2.0	
PHYSICAL DATA	A	Ft^2	1520.534		2460		4072	
PHYSICAL DATA	$\sigma = \frac{bc}{\pi R}$		.0651086		.06217			
PHYSICAL DATA	V_t	FPS	594.391		647			
PHYSICAL DATA	$\rho A V_t^2$ (ρ = .002378)		1,277,475		2,445,607			
PHYSICAL DATA	Ω	RPM	258		221		185 → 204	
PHYSICAL DATA	ω	Rad/Sec	27.01776		23.1313			
PHYSICAL DATA	c	Ft	1.5		1.37		1.792	
PHYSICAL DATA	R	Ft	22		28		36	
PHYSICAL DATA	i_F	Deg	9.5		3.0			
PHYSICAL DATA	i_R	Deg	9.5		0			
PHYSICAL DATA	I_F	Slug-Ft^2	410		1050		3480	
PHYSICAL DATA	I_R	Slug-Ft^2	410		0			
PHYSICAL DATA	M_{wF}	Ft Lb	1125		2020			
PHYSICAL DATA	M_{wR}	Ft Lb	1125		0			
PHYSICAL DATA	$K_F\, e\, b/2$	Ft Lb	14665					
PHYSICAL DATA	$K_R\, e\, b/2$	Ft Lb	14665					
PHYSICAL DATA	θ_t	Deg	-7.0		-8.0		-8.0	
PHYSICAL DATA	r	Ft	5.0					
AERO	M_s	Ft Lb/In	16780		4050		4800	
AERO	L_i	Ft Lb/In	1878		4100		6250	
AERO	N_r	Ft Lb/In	7900		5000		33500	
AERO	$\dot{q}$	Deg/Sec^2/In	10.78		14.32		5.83	
AERO	$\dot{p}$	Deg/Sec^2/In	24.55		18.44		16.35	
AERO	$\dot{r}$	Deg/Sec^2/In	5.08		13.24		17.6	
AERO	Flat Plate $D/q = f_x$	ft^2	38		37		60	
AERO	f_y		350		330		400	
AERO	f_z		129		80		490	

Longitudinal Equations of Motion and Stability Derivatives for a Tandem Helicopter - Reference (2) Vertol IBM Program 219

This program calculates the longitudinal stability derivatives that are used in the Analog Study of the aircraft recovery operation. These derivatives prescribe the response of the prime mover to a longitudinal disturbance of the system from the trim flight regime. The program calculates the derivatives for any chosen combination of helicopter geometry, weight, center of gravity, altitude and airspeed. The results of this program have been correlated with flight test data from the Boeing-Vertol H-21, Model 44, Model 107 Prototype and YHC-1A.

Lateral - Directional Equations of Motion and Stability Derivatives for a Tandem Helicopter - Reference (3) - Vertol IBM Program No. 224

The lateral directional program uses the outputs of the longitudinal trim analysis to calculate the lateral and directional stability derivatives that are used in the Analog Study. These derivatives prescribe the response of the prime mover to a lateral or directional disturbance of the system from the trim flight regime.

Load Rotation Analysis - Derivation Contained in Appendix II

In addition to the conventional helicopter stability programs described above, it was necessary to develop an analysis for external load rotation under the prime mover helicopter. A strip integration technique was employed to calculate the load rotation moments that are developed by the rotor slipstream swirl. The analysis provides design information for the solution of the load rotation problem of hover and slow forward flight. The analysis was substantiated by correlation of results to a flight test film of an H-34 prime mover hovering with an H-21 fuselage as the external load. Derivation of the analysis and the correlation with the flight test film is contained in Appendix II (Volume II).

Definition of Prime Movers

The prime movers considered were the H-21, H-34 and H-37. For study purposes, the prime mover capabilities were calculated for a minimum flying weight that does not require stripping of major equipment. Military performance evaluation reports were consulted for minimum operational gross weights and maximum hover-out-of-ground effect gross weights (sea level standard ambient conditions). A summary of the prime mover capabilities is contained in Table VII. The external load capabilities are intended to be representative and do not necessarily constitute maximum capabilities. Variations in ambient condition can increase or decrease these capabilities.

TABLE VII - PRIME MOVER CAPABILITY

	H-21C	H-34	H-37
Empty Aircraft	8,550	7,205	
Engine Oil	146	96	20,967
Transmission Oil	56	54	
Trapped Fuel and Oil	45	49	
Control Boost System	58	-	-
Miscellaneous	35	35	35
Minimum Aircraft Weight	8,890	7,439	21,002
1.5 Hour Fuel @ 60 kt Cruise	1,200	680	1,800
Crew (3)	600	600	600
Minimum Mission Flying Weight	10,690	8,719	23,402
Vertical Fin Kit	100	100	100
Sling Kit Including Mechanical Yaw Restraint	141	141	200
Minimum Recovery Mission Weight	10,931	8,960	23,702
Maximum G. W. Hover OGE	14,350	12,500	30,939
Maximum Sling Load	3,419	3,540	7,237
Maximum Possible Download for an H-21 Load with no Prime Mover Interference Effects	613	661	987
Nominal Maximum Aircraft Recovery Load (Allows for Download Interference Effect of Prime Mover)	3,000	3,000	6,900

Definition of Prime Movers, Continued

Download due to rotor downwash will reduce the useful external load that can be lifted. Numerous combinations of these variables necessitated the establishment of a standard approach. The downwash values of Table XII are the maximum possible if no interference effects due to the prime mover fuselage existed.

Since directional restraint of the load in hover will position the load nearly parallel to the prime move fuselage, the interference effect will alleviate the downloads shown in Table VII. (Furthermore, maximum downloads for the majority of other recovered aircraft will be less than the values cited for the H-21 in Table VII). Estimates of actual download for the aircraft recovery operation led to establishing the nominal load capabilities of Table VII. These nominal limitations were used to prepare the recovered aircraft strip lists that are contained in Charts SK10911 through SK10921, included in this report. However, for analysis of the problem it was necessary to investigate higher loads that might be expected under more favorable than standard ambient conditions. Therefore, study load limitations were selected as the maximum sling load i.e. neglecting download.

Definition of Recovered Aircraft

Recommended strip lists for the recovered aircraft are contained in the suspension configuration drawings of this report (SK10911 through SK10921). However, in the analysis, a range of gross weights must be considered since damage to the recovered aircraft is an indeterminate that introduces an infinite number of possible stripping requirements.

Selection of Study Combinations of Prime Movers and Recovered Aircraft

The Army aircraft that are considered by this investigation are listed in Table VIII.

Table VIII. Prime Movers and Recoverable Aircraft Considered

Prime Mover	Recoverable Aircraft		
H-21	L-19	H-13	H-34
H-34	L-20	H-19	H-37
H-37	L-23	H-21	HU-1A
	U-1A	H-23	

Study of all combinations of these aircraft in recovery operations would result in redundant solutions.

TABLE IX

PARAMETRIC LOAD ANALYSIS

$$\text{RELATIVE LOADING PARAMETER} = \frac{\text{WEIGHT OF A/C RECOVERED}}{\text{MISSION WEIGHT OF PRIME MOVER}} = \text{R.L.P.} \qquad \text{\% MAX LOAD} = \frac{\text{WEIGHT OF RECOVERED AIRCRAFT}}{\text{MAXIMUM EXTERNAL LOAD OF PRIME MOVER}}$$

AIRCRAFT TYPE	H-21 MAX LOAD = 3569 LBS (1) R.L.P.	H-21 % MAX LOAD	H-34 MAX LOAD = 3716 LBS (1) R.L.P.	H-34 % MAX LOAD	H-37 MAX LOAD = 7345 (1) R.L.P.	H-37 % MAX LOAD	DIRECTIONAL (2)* PARAMETER	LIFT (3)* PARAMETER
L-19	0.1417	42.8	0.1740	40.2	0.0652	20.8	.245	.242
L-20	0.2970	89.6	0.3640	86.2	0.136	43.6		
L-23	0.3260	98.2	0.418	98.8	0.1703	54.3		
U-1A	0.3220	97.2	0.4090	96.7	0.2070	66.0		
HELICOPTER TYPES								
HU-1A	0.2590	78.5	0.3180	76.4	0.1195	38.2	.0517	0.90
H-13	0.1432	43.3	0.136	41.6	0.0659	21.0		
H-19	0.3150	95.2	0.386	91.4	0.2405	76.8	-	-
H-21	0.3260	98.5	0.401	94.6	0.2740	87.3	.1835	2.50
H-23	0.2410	72.8	0.296	70.0	0.1110	35.4		
H-34	0.3160	95.5	0.388	91.8	0.292	93.1	1.128	0
H-37								

NOTE: For analysis purposes, the load weights and prime mover capabilities used in this table reflect maximum effort missions and were not limited to the nominal loads of Table VII.

(1) HOVER OUT OF GROUND EFFECT

(2) $\dfrac{\text{DIRECTIONAL STABILITY DERIVATIVE*}}{\text{DIRECTIONAL MOMENT OF INERTIA}}$

(3) $\dfrac{\text{PITCH STABILITY DERIVATIVE*}}{\text{PITCH MOMENT OF INERTIA}}$

*UNDAMAGED AIRCRAFT

A judicious selection of representative combinations provides sufficient analytical background to solve not only all combinations, but also variations of the combinations that result from different suspension configurations and damage to the recovered aircraft.

One method employed in choosing the specific prime mover - recovered aircraft combinations is a parametric analysis that indicates problem combinations. The parametric analysis considers the performance capabilities of the prime movers, the directional characteristics of the undamaged loads, and lift due to pitch of the undamaged load (See Table IX). Emphasis was also placed on choosing a representative sample of aerodynamic types as recovered aircraft, i.e., tandem rotor, single rotor and fixed wing.

A second method employed in choosing the specific combinations relies on the basic dynamic response of the prime movers. Study of the H-37 and H-34 longitudinal and lateral dynamic responses reveals a similarity that prevails among single rotor type helicopters. This is due, in part, to a highly effective horizontal tail in the longitudinal response and a lateral response that is largely dependent upon the powerful directional contribution of the tail rotor. In contrast, the response of a tandem helicopter to longitudinal and lateral disurbances are dominated by the effects of the rotors and the principal axis inclination. More specifically, the pitch response of a single rotor type helicopter to a longitudinal disturbance from trim flight is oscillatory divergence, while the tandem rotor response is pure divergence. In the lateral mode, the single rotor response to a lateral distrubance from trim flight is critically damped while the tandem response is oscillatory divergence. Figure 3 depicts typical time histories of the dynamic responses of the H-37, H-34 and H-21 prime movers. Examination of Figure 3 reveals the similarities between the dynamic responses of the H-34 and the H-37 and the dissimilarities between the H-37 (or the H-34) and the H-21.

Consideration was also given to the problem combinations that were revealed by the historical review.

Applying these considerations to the prime movers and the recoverable aircraft listed in Table VIII, the selected study combinations are listed in Table X.

Table X Selected Study Combinations of Prime Mover Recovered Aircraft

Prime Movers	Recoverable Aircraft	
H-21	L-19	H-21
H-34	L-23	H-34
		HU-1A

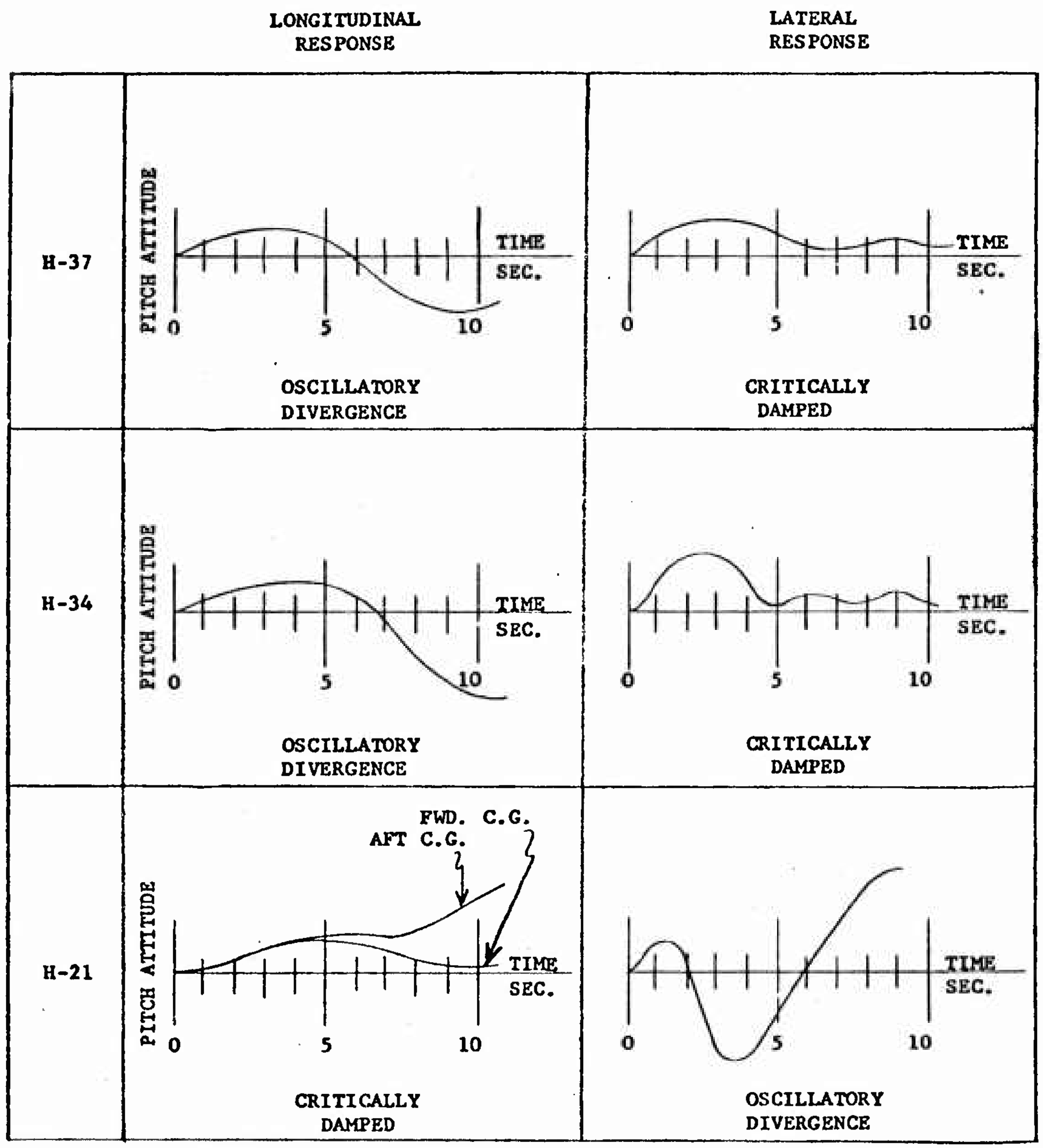


FIGURE 3

TYPICAL LONGITUDINAL AND LATERAL DYNAMIC RESPONSES TO A PULSE INPUT

ANALYSIS OF THE PROBLEM, Continued

The selection of the H-21 prime mover represents the tandem rotor dynamic characteristics. The H-34 prime mover represents the single rotor dynamic characteristics. Since the H-37 would have the same basic dynamic characteristics as the H-34, but would be operating at a much lower relative load factor, as indicated by the parametric study of Table XI, the H-37 was eliminated from the detailed study that follows.

The recoverable aircraft selected represent the basically different types of recoverable aircraft, i.e., L-19 and L-23 fixed wing, H-21 tandem, and H-34 and HU-1A single rotor. These selections, with the exception of the L-19, require that the H-21 and H-34 prime movers operate near their maximum external load capacities.

ANALOG COMPUTER ANALYSIS PROCEDURE

The analog study is performed by initiating a one-inch/one-second control stick pulse to the trimmed condition of either hovering flight or 50 knots cruise flight. To provide a basis for comparison, the stick pulse response of the basic prime mover is first demonstrated. The general characteristics displayed in this dynamic test are substantiated by correlation with Edwards Air Force Base Phase IV stability tests (References 19 and 20). Significance of the analog time histories of the prime movers will be discussed later in this report. Corresponding stick pulse response for each of the selected prime mover-load combinations (Table X) is then investigated. (The combination of the L-23 aircraft with either prime mover has been omitted owing to unavailability of pertinent physical parameters of that aircraft.) Due to the number of cases, the responses of selected combinations are presented as Appendix IV in Volume II of this report.

In addition to the above program, an experiment was made in "flying" the two prime movers, each with an H-21 external load, on an improvised flight simulator. The purpose was to explore feasibility of simulating pilot reaction to the different flying qualities of prime mover-external load combinations. Examples of the analog traces depicting results of the experiment are shown in Volume II, Appendix IV, pages IV-10 and IV-11. The flight simulator technique is valuable in depicting the effects of voluntary pilot control. This could be true particularly if it were desired to test feasibility of specific recovery operation before exposing flight and ground personnel to unknown risks.

The analog studies of the recovery of an H-21 fuselage by H-21 and H-34 prime movers were extended to explore the effects of five important variables:

1. External load weight was examined from the conservative maximum value of 3,500 pounds to a relatively light load of 1,700 pounds.

2. Varying degrees of restraint between the prime mover and the external load were investigated. These restraints were initially directed toward studying the merits of reducing the number of degrees of freedom in the pitch and roll motions of external load with respect to the prime mover hook.

   Restraint studies were then extended to evaluate the effects of coupling the load to the prime mover in the directional mode by means of a mechanical spring. The mechanical yaw restraint was varied from zero to a practical maximum of 30,000 ft lb/rad.

3. Aerodynamic directional characteristics of the load were varied to simulate damage, center of gravity movement and several vertical

tail configurations. The directional parameter of an H-21 load was varied from -30,000 ft lb/rad to +30,000 ft lb/rad.

4. An investigation was conducted on all combinations of mechanical yaw restraint and aerodynamic directional characteristics.

5. The effect of cable length of the multiple-cable suspension system was investigated. Cable lengths were varied to provide distances of 10 feet to 30 feet between the center of gravity of the load and the prime mover hook.

EVALUATION OF ANALOG COMPUTER ANALYSIS

To properly evaluate effects of external loads on stability of the prime movers, an understanding of the equations of motion as they apply to stability studies of the basic prime movers is necessary. Without presenting a rigorous discussion of helicopter stability, a fundamental insight can be obtained from recognition of the significance of certain key indicators. A previous discussion on Page 42 described the characteristic dynamic responses to H-21 and H-34 helicopters to disturbances from trimmed flight. Now the significant physical parameters of these aircraft will be related to significant stability derivatives that are inputs to the equations of motion. For example, in regard to longitudinal responses of the H-21 and H-34, mention was made of the significance of horizontal tails, rotors, etc. These physical characteristics are represented in the longitudinal equations of motion by stability derivatives. The longitudinal stability derivatives that represent the significant physical characteristics are:

1. Pitching moment due to changes in angle of attack (M_{α});

2. Pitching moment due to change in forward speed (M_u).

To illustrate the significance of these parameters, a brief discussion of Figure 4 is presented.

In Figure 4 the key longitudinal stability derivatives are represented by the ordinate (M_u) and the abscissa (M_{α}). The stability boundaries labeled (A) and (B) represent the effect of the less significant stability derivatives. (A summary of longitudinal stability derivatives is contained in Table IV). (A) and (B) can be shifted or rotated by changes in the stability derivatives other than M_u and M_{α}. Entering Figure 4 with combination of M_u and M_{α} that fall on the stability boundary (A), the dynamic response is depicted by the time history of (C). For most combinations of positive M_u and positive (or slightly negative) M_{α}, the response is oscillatory divergence (F). Examination of the M_{α} and M_u forward flight stability derivatives or the H-34 (Table IV) reveals that the response is slightly to the right of the stability boundry (A); i.e., oscillatorily divergent. The H-21 M_u - M_{α} terms position the response in the lower right quadrant, i.e., pure divergence (G). These responses are consistent with the discussion of Figure 3. The analog traces of the basic prime movers are presented in Appendix IV of Volume II (H-34 basic, Page IV-7 , H-21 basic, Page IV-29).

To discuss the effect of external loads on the longitudinal dynamic response, attention is invited to the equations of motion (Table I). Terms C_5, C_7, and C_8 are the important M_{α} and M_u terms. The C_5 (M_{α})

term contains a powerful negative contribution resulting from the external load weight. The effect of the load weight on the C7 (M_u) term is to reduce the magnitude. As shown in Figure 4, it is obvious that the M_α - M_u combination is approaching the negative M_α axis, i.e., a convergent response. The change in the response characteristic is in relation to the weight of the external load. The investigation of load weights from 1,700 pounds to 3,500 pounds did not reveal any stability problems.

Two cable suspension configurations were studied (Ref. Figure 2). The multiple cable suspension reduces the number of degrees of freedom of the system. Multiple cable suspension indicates a marked improvement in the dynamic response of the system. This improved response is especially desirable with loads that have high lift capabilities (even if suppressed by lift spoilers) where large pitch and roll amplitudes introduce undesirable aerodynamic forces to the forces to the system. The dynamic response improvement afforded by the multiple cable suspension is illustrated by time histories contained in Appendix IV. (Example: H-34 prime mover with H-34 load App. IV, Pages 15 and 16).

Study of several cable lengths (more specifically the distance from the hook of the prime mover to the center of gravity of the load of a multiple cable configuration) established a design limitation of 20 feet for loads exceeding 2,500 pounds. At cable lengths between 10 and 20 feet, the dynamic character of all conceivable combinations of aerodynamic characteristics of the load are within an acceptable range. However, as cable length becomes greater than 20 feet, the dynamic response deteriorates rapidly for some combinations of load aerodynamic characteristics. This influence of cable length is depicted by the analog traces of Appendix V.

Discussion of the effects of external loads on prime mover stability has heretofore been confined to point mass or undamaged aircraft. Discussion will now be directed toward the influence of the six component aerodynamic characteristics of the external load, i.e., drag, lift and side forces and roll, pitch and yaw moments.

The drag force of the external load is most important from a performance penalty consideration. Power required is an output of the longitudinal trim analysis. Power required for the recovery mission by the H-21 and H-34 prime movers established the 50 knot speed that was used through much of the aircraft recovery investigation. This 50 knot limit is prescribed by drag penalties imposed by external loads, such as an H-21 or H-34 with suspension paraphernalia and operation of the prime mover at normal cruise power.

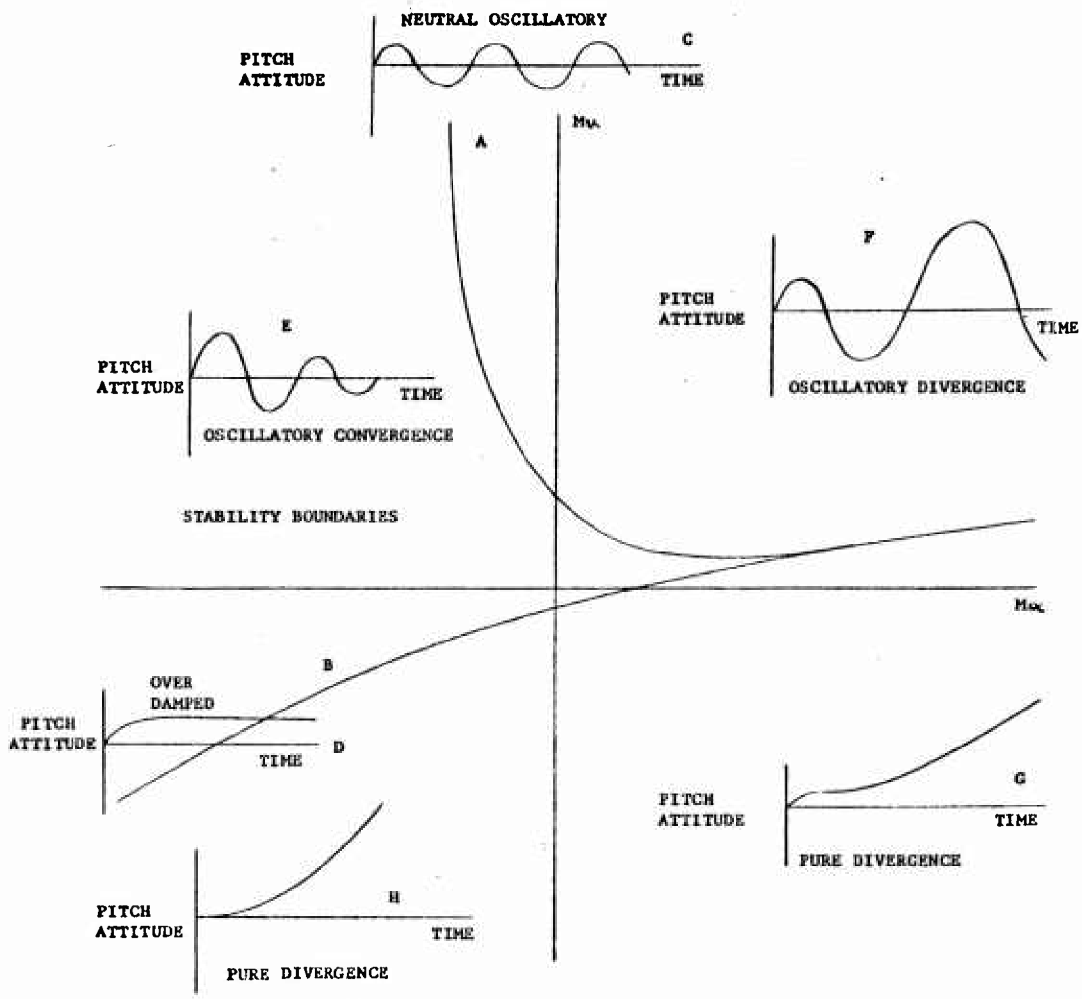


FIGURE 4 FORWARD FLIGHT DYNAMIC LONGITUDINAL STABILITY

Smaller loads such as the L-19 could, from a performance criterion, be carried at higher speeds, but to normalize the dynamic investigation the small loads were also studied at 50 knots.

The drag of the external load will result in a trim pitch attitude of the load that is different from the hover pitch attitude. For an H-21 suspended 15 feet from the prime mover hook, the 50 knot trim cable angle and change in load pitch attitude will be 5^o from the hover position. It is, therefore, desirable to rig the load slightly nose up in hover. All other load drag angles can be estimated for 50 knots by the product of 5 degrees and the ratio of the drag flat plate area to the H-21 drag flat plate area of 38 square feet. For different speeds, the above angle would be multiplied by the ratio of the desired speed in knots squared to 50 knots squared.

$$\text{Trim Cable Angle from Vertical} = \text{Pitch Angle Change from Hover} = \frac{\text{Flat Plate Area}}{38} = \frac{\text{Speed Squared}}{50^2} \times 5$$

$$= \frac{\text{Flat Plate Area X Speed Squared}}{19000} \qquad \text{(Equation 1)}$$

The significance of this cable angle becomes apparent when the drag characteristic of an H-21 fuselage is examined versus pitch attitude. For example, rig the H-21 fuselage 5 degrees nose down in hover. At 70 knots the trim pitch angle could be:

$$\text{Trim Pitch Angle}^* = \frac{50 \text{ X } 70^2}{19000} = 13^o \qquad \text{Trim} = 13^o + 5^o = 18^o \text{ nose down}$$

* Must be solved iteratively since flat plate area is a function of pitch angle.

At 70 knots this pitch angle would result in a power penalty of:

$$\text{Power} = \frac{V^3}{146600} = \frac{(50-38)(70 \text{ X } 1.15)^3}{146600} = 43 \text{ Horsepower} \qquad (V \text{ - knots})$$

(Equation 2)

At 50 knots the power penalty would be considerably less. It is therefore concluded that the load should be rigged slightly nose up in hover, but considerable deviations from optimum will not result in excessive performance penalties for speeds in the range of 50 knots.

Drag also provides a damping characteristic in the longitudinal equations of motion. The magnitude, however, is relatively insignificant compared to the mass contributions of the external load.

One further influence of drag is in the important M_u term of the equations of motion. The contribution of drag of the external load to the M_u term is negative, which moves the system toward the pure divergent quadrants of Figure 4. This effect negates the favorable influence of the external load mass on the M_u term. Stated simply, drag of the external load produces a trim nose down moment. With increasing speed the nose down moment increases.

The lift due to pitch that can be developed by helicopter fuselages can be considered negligible compared to the mass contributions of the external load. Fixed wing aircraft, however, when complete with wings can develop sufficient lift to jeopardize the recovery operation. A case of an L-19 generating lift great enough to cause inadvertant hook release is recorded in the historical review of this report. It is recommended that lift spoilers be secured to wings to preclude the possibility of the load flying up into the prime mover. In addition to spoilers, the multiple cable suspension configuration provides pitch stability to the load that results in smaller amplitude of the load pitch attitude, therefore reducing lift. (See discussion of pitching moment below).

Load side force is so closely related to yaw that it will be discussed with load yaw moment.

Load pitching moment can be a serious problem if the load does not possess inherent pitch stability. Horizontal tails provide the primary source of pitch stability. One problem of pitch instability was noted in the discussion of lift. A special problem arises in pitching of long unstable fuselages (such as an H-21 without tails) which are more prone than the shorter loads to strike the fuselage of the prime mover. Since it is extremely likely that the recovered aircraft has sustained damage of the horizontal tail, it is necessary to provide pitch stability to the load by another means. This is accomplished by the multiple cable suspension configuration. The principle of this solution is that the load is forced to rotate about the apex of the suspension and cannot readily rotate about its cg. This means that the load weight provides the pitch stability and is therefore not directly dependent upon aerodynamic forces.

The same argument used for pitch stability of the load can be applied to roll stability of the load. Therefore, the multiple cable suspension configuration is also recommended for lateral restraint of the load.

Load yaw moments coupled with side force due to sideslip create the most formidable problem of the aircraft recovery operation. Background for the discussion of the problems associated with directional stability of the external load will be presented first.

Damage sustained by the recoverable aircraft could include destruction of the vertical tail. The general effect of removing the vertical tail is depicted by Figure 5a. The typical airplane characteristic represents a stable restoring moment for yaw displacements from the origin (Solid line of Figure 5a). This force can be compared to the restoring force of a ball in a cup (see Figure 6a). As shown in Figure 5a, the effect of removing vertical tails results in an unstable directional moment for yaw displacements near the origin. This is analogous to the modified unstable equilibrium of Figure 6d. However, it should be noted that a stable restoring moment exists at $\pm 30^{\circ}$ from the zero yaw position. Trim about the 30° yaw angle will produce drag and side forces that must be overcome by control powers of the prime mover. Oscillations about the 30° yaw angle can conceivably force the pilot to operate near the control limits of the prime mover or reduce forward speed. Figures 5b and 5c depict the influence of cg movement on the directional characteristics of the typical airplane. Figure 5b indicates that the desirable restoring moment of the typical airplane becomes more powerful as the cg moves forward. (This is analogous to deepening the cup of Figure 6a). Too much directional stability of the load will not create problems for the aircraft recovery operation. The forward cg without tails could result in wandering between $\pm 25^{\circ}$. (This is analogous to Figure 6e).

When a damaged aircraft is prepared for recovery, it is often necessary to remove equipment for weight reduction. As equipment is removed, the cg will shift. This resultant cg is easily calculated if the initial weight and cg station are known and the weight and station of removed equipment are known.

$$\begin{array}{l}\text{(Resultant cg)} = \\ \quad\text{Station}\end{array} \quad \frac{\begin{array}{c}\text{(Initial cg)}\\\text{Station}\end{array} \times \begin{array}{c}\text{(Initial)}\\\text{Weight}\end{array} - \begin{array}{c}\text{(Removed Item)}\\\text{Station}\end{array} \times \begin{array}{c}\text{(Removed Item)}\\\text{Weight}\end{array}}{\text{(Initial Weight)} - \begin{array}{c}\text{(Removed Item)}\\\text{Weight}\end{array}}$$

(Equation 3)

Usually stripping will move the cg aft. The aerodynamic result of moving the cg aft is depicted by Figure 5c. The consequences are that the basic restoring moment is reduced in magnitude (more shallow cup of Figure 6a) and the "without tails" configuration becomes more undesirable than the normal cg characteristics of Figure 5a. For

example, examine the drag penalty at 50 knots of flying the H-21 broadside to the direction of flight. The H-21 fuselage without tails can be considered a cylinder. A cylinder will stabilize at 90 degrees of yaw which results in a drag flat plate area of 350 square feet.

$$\text{Delta Power} = \frac{(350 - 38)\ (50 \times 1.15)^3}{146{,}600} = 405 \text{ Horsepower}$$

(Ref. Equation 2)

Power required by the H-21 prime mover with a 3500 pound H-21 external load at minimum drag sideslip angle is about 1000 horsepower which is about normal cruise power. It is immediately obvious from a forward flight performance consideration that it is desirable to prevent excessive trim yaw angles of the recovered aircraft.

To solve the directional problem of the external load it is necessary to investigate the characteristics of the load throughout the mission flight envelope. For discussion purposes the flight envelope will be divided into three flight regimes:

1. Hover
2. Transition
3. Forward Flight

The problem in hover is load rotation. Under single rotor type prime movers the load will rotate due to the downwash swirl of the rotor slipstream. The magnitude of the rotational moment on an H-21 fuselage suspended from an H-34 prime mover is 650 foot pounds. This moment was calculated for the H-34 - H-21 recovery operation as representative of the maximum rotational moment that can be expected for aircraft recovery operations with the H-34 prime mover. For the H-37-H-21 recovery mission the hover moment will be 1700 foot pounds. The load rotation problem under the H-21 prime mover is not as serious. Under the H-21, the load will stabilize at a 90^{o} yaw angle with the prime mover. This is due to the nature of the downwash of the tandem rotor configurations. Figure 7 depicts the downwash swirl patterns of the single and tandem rotor configurations. Note that if the external load were symmetrically suspended about the center line of rotors of the tandem prime mover, there would be no tendency for the load to rotate from a position parallel to the prime mover fuselage. However, the load is generally not symmetrical about the center line or rotors, therefore, it will rotate slowly at first due to the unbalanced downwash moment and will then stabilize at 90^{o}. The magnitude of the H-21 load rotation moment is considerably less than that of the H-34. To solve the hover load rotation for the H-21 and the H-34 prime movers the design criterion is the 650 foot pound moment of the H-34. Providing sufficient yaw restraint of the external load to solve the

H-34 problem will be more than adequate for the H-21 prime mover.

In transition flight the load rotational moment of the H-34 prime mover with an H-21 load will at first diminish as the wake angle of the slipstream increases with increasing forward speed. At a point when the wake angle positions the forward portion of the slipstream at the aft end of the load, the rotational moment would be approximately one half the magnitude but opposite in direction (depending upon suspension cable length, the flight speed when maximum rotation moment reversal occurs will be about 25 knots). For the H-34 prime mover, with an H-21 load, the maximum requirement for preventing load rotation due to slipstream swirl in hover or transition is therefore $\pm$650 foot pound of stabilizing moment. The transition design criteria must also incorporate the forward flight aerodynamic forces on the external load that will be developing proportional to the square of the speed. These forces will be stabilizing or destabilizing according to the directional characteristics of the load.

In forward flight the major problem will be directional stability of the load. A minimum of directional stability that is considered acceptable will be the directional stability that is inherent to the undamaged aircraft complete with all tail surfaces. In the cases where damage to or removal of the vertical tail has occurred, the design of the recovery equipment must provide load directional restraint of the order of magnitude of the original vertical tail.

Three practical design concepts that would provide solutions to the load yaw restraint problems of the recovery mission are:

1. Mechanical restraint between the load and the prime mover by means of a nonswiveling hook. Due to the multiple cable suspension, a torsional spring effect will result. This spring effect would be designed to negate any directional instability of the load in forward flight and preclude load rotation due to slipstream swirl in both hover and transition flight regimes.

2. An aerodynamic solution to the forward flight problem is to replace or augment the existing vertical tails by flat plate vertical tail kits that will provide a desirable forward flight directional stability. The tail surfaces would be designed as lift surfaces directed up into the rotor downwash. The lift developed would produce a restoring moment to the load in hover. Flaps would be necessary to provide sufficient control power to maintain load stability in hover and through transition.

3. A combination of the mechanical and aerodynamic yaw restraint system would be designed to provide sufficient mechanical

restraint to prevent load rotation in hover and transition with aerodynamic fins providing the directional stability in forward flight. Based on the requirements of the H-21 external load, the mechanical yaw restraint requirement would be 1700 foot pounds (under the H-37 prime mover). The vertical tails would be larger than the standard H-21 vertical tails since they would probably be placed forward of the normal location. The recovery kit tails would be adaptable to other aircraft besides the H-21. In many operations the directional restraint would be more than adequate (an L-19 for example). However, too much directional stability has never been a problem in the analog studies.

One other concept given preliminary consideration was a two point suspension configuration. This, however, was quickly eliminated from detailed consideration due to undesirable safety compromises.

Evaluation of the three proposed design concepts over the flight envelope provides the basis for selecting the final system. Figure 8 is a summary of this evaluation.

MECHANICAL EVALUATION

The evaluation of mechanical concept (Figure 8a) indicates no problems in hover or transition. However, the system would be speed-limited depending upon the magnitude of the directional instability of the external load. The mechanical yaw restraint remains constant with forward speed while the load instability increases with the square of the forward speed. (See analog studies of Appendix VI).

AERODYNAMIC EVALUATION

The aerodynamic concept provides a satisfactory solution to the hover and forward flight regimes (Figure 8b). However, in the transition regime, the reversal of the slipstream rotation in the area of the tail fins will aggravate the transition load rotation problem.

AEROMECHANICAL EVALUATION

This system provides load yaw restraint in all flight regimes. Extensive analog investigations of this system revealed no problems.

FIGURE 5

RECOVERED AIRCRAFT AERODYNAMIC

DIRECTIONAL STABILITY

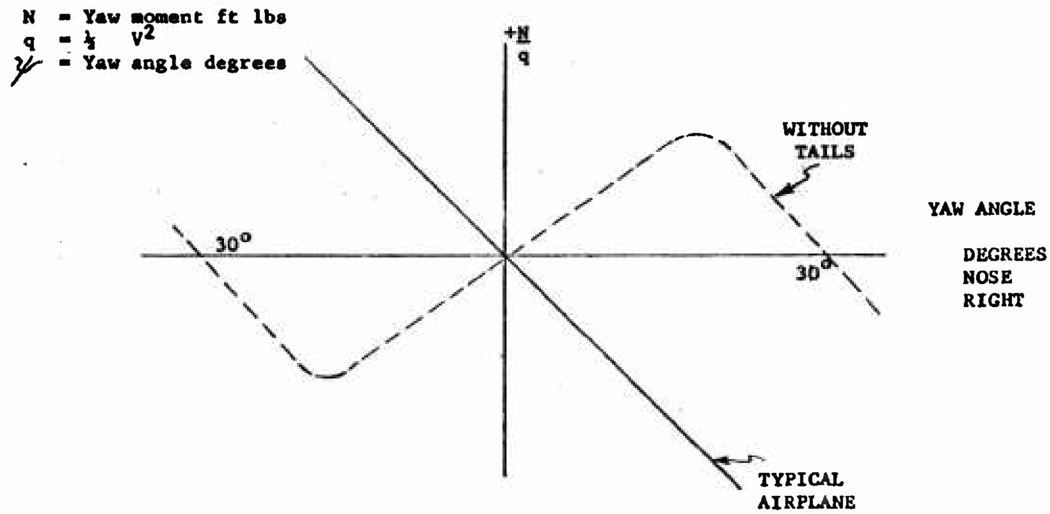


FIGURE 5(a) NORMAL C.G.

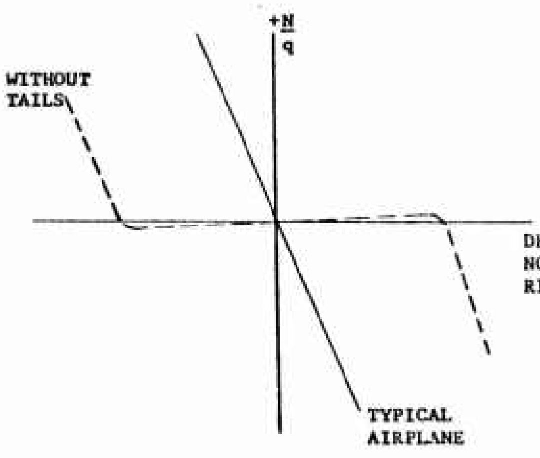


FIGURE 5(b) FORWARD C.G.

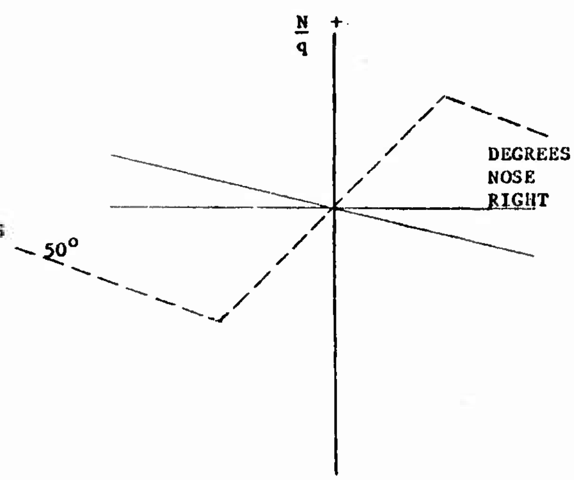


FIGURE 5(c) AFT C.G.

FIGURE 6

MECHANICAL ANALOGY OF DIRECTIONAL STABILITY

STATIC STABILITY

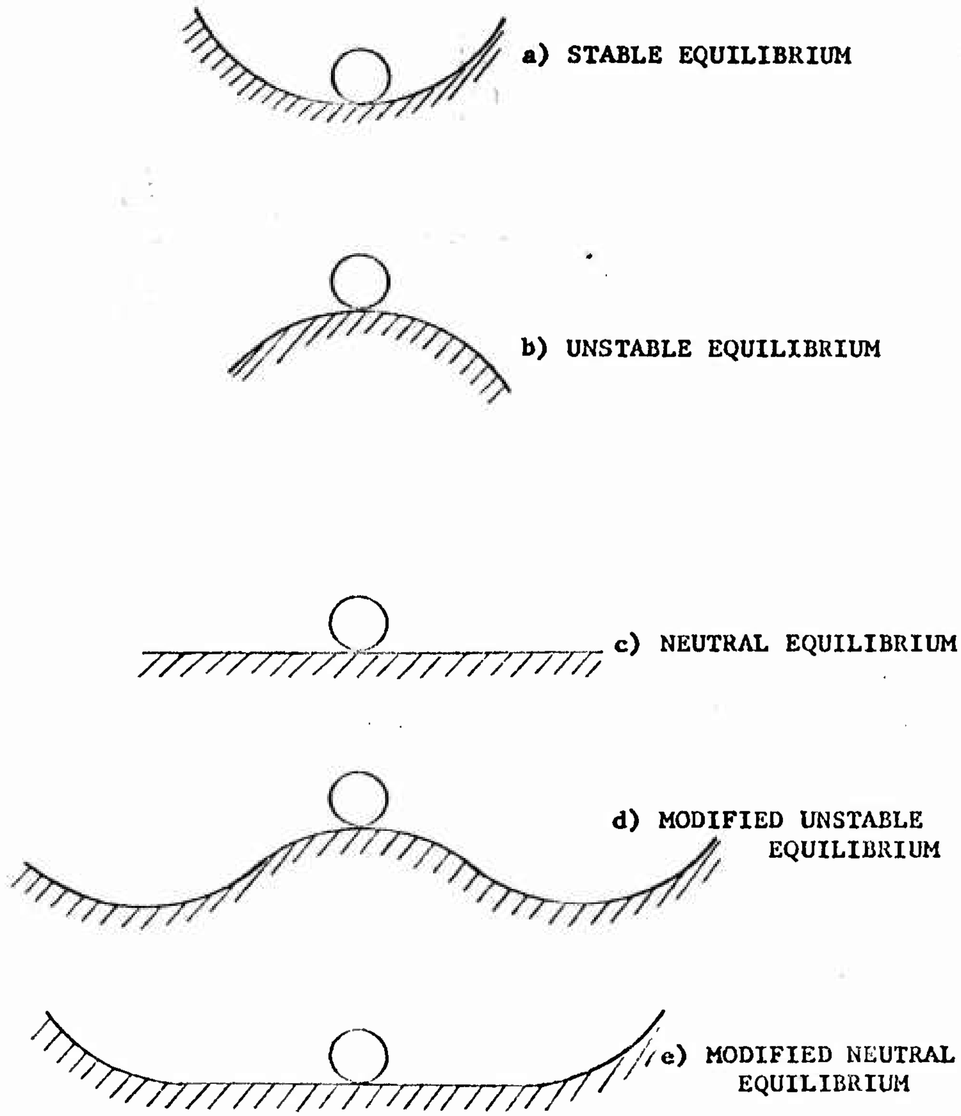


FIGURE 7 HELICOPTER ROTOR DOWNWASH RELATIONSHIP TO LOAD ROTATION

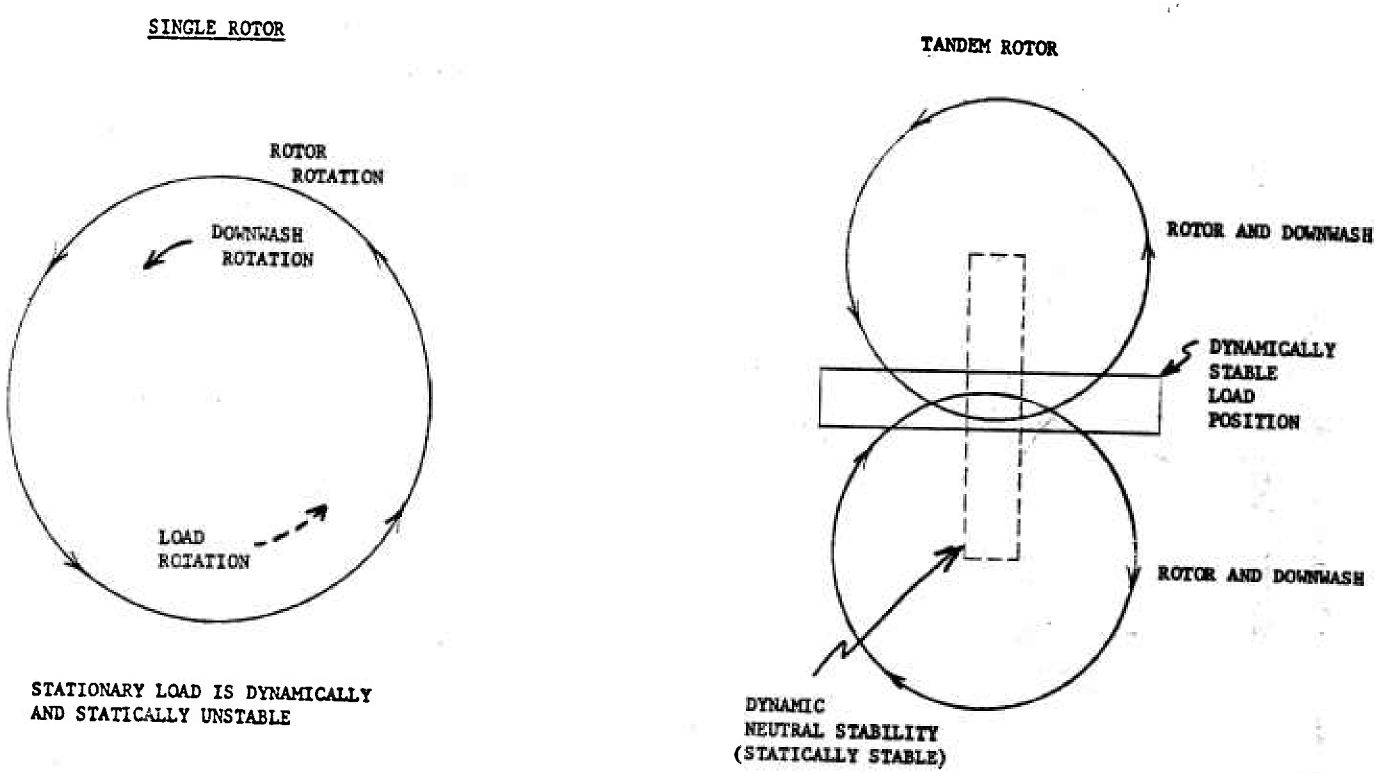
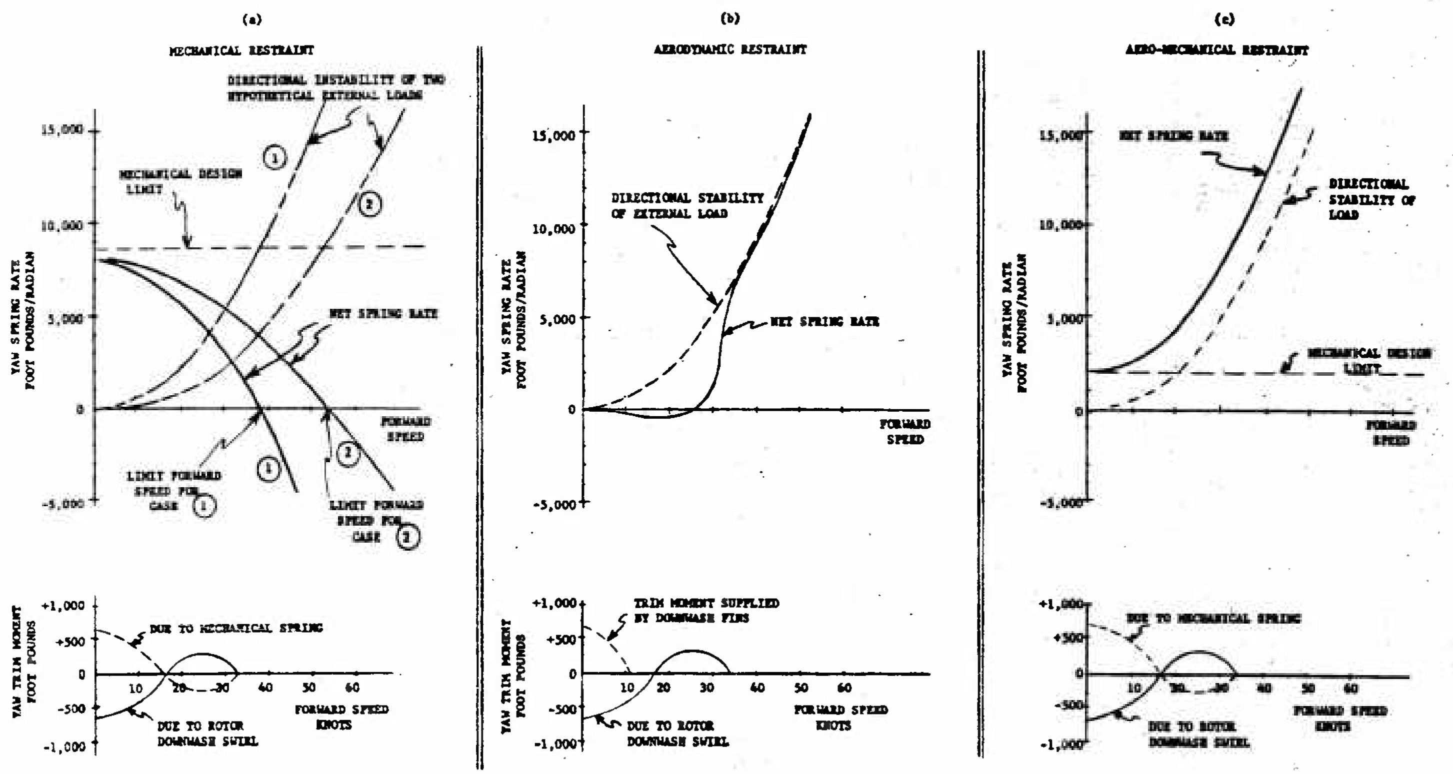


FIGURE 8 AIRCRAFT RECOVERY YAW RESTRAINT SUMMARY



NOTE: NEGATIVE YAW SPRING RATE IMPLIES DIRECTIONAL DIVERGENCE OF THE LOAD.

PRELIMINARY DESIGN OF RECOVERY SYSTEM

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The preliminary design effort has been correlated with the historical record surveys and analytic studies discussed in earlier sections of this report. Results of the design work are presented herewith in narrative form and in a series of design layouts, engineering sketches, charts and tables. This section, besides introductory general discussion, includes the following topics:

(1) Logistic Considerations for Design of Recovery System
(2) Design Concept for Aircraft Recovery System (Suspension and Restraint of Recovered Aircraft)
(3) Structural Design Data for Recovery System

Drawings and charts associated with the various aspects of the design effort are identified by number and title as follows:

SK10910	Kit Components, Aircraft Recovery System
(Sheet 1)	Suspension Components and Mat
(Sheet 2)	Yaw Restraint Connection
(Sheet 3)	Stabilizing Fin Kit
SK10911	Sling Configuration, H-13 Recovered Aircraft
SK10912	Sling Configuration, H-23 Recovered Aircraft
SK10913	Sling Configuration, HU-1A Recovered Aircraft
SK10914	Sling Configuration, H-19 Recovered Aircraft
SK10915	Sling Configuration, H-34 Recovered Aircraft
SK10916	Sling Configuration, H-21 Recovered Aircraft
SK10917	Sling Configuration, H-37 Recovered Aircraft
SK10918	Sling Configuration, L-19 Recovered Aircraft
SK10919	Sling Configuration, L-20 Recovered Aircraft
SK10920	Sling Configuration, L-23 Recovered Aircraft
SK10921	Sling Configuration, U-1A Recovered Aircraft
SK10447	Proposed Recovery Procedure, Disabled Aircraft
SK10452	Gantry, Aircraft Recovery

Additionally, data tables are employed to present pertinent design information, as indicated below.

Table XI	Index for Symbol Code Applied to Aircraft Recovery Cases
Table XII	Summary List of Aircraft Recovery Cases
Table XIII	Structural Design Criteria, Aircraft Recovery System

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Table XIV Summary of Stress Analysis Data, Aircraft Recovery System

Design work has been undertaken with consideration of a broad range of problems pertaining to aerial aircraft recovery operations. Certain problems encountered during preparation and hook-up of the downed aircraft for aerial evacuation are discussed under "Logistic Considerations."

However, the major cause of actual mission failure, as indicated by the historical record survey, stems from "in-flight" characteristics of the recovered aircraft. Primary concern of the analytic studies in this report is therefore to define these in-flight problems and to mathematically test methods for creating stable and controllable prime mover-load coupled systems.

Recognition is made of the contribution of the Nems Clarke Company, under Contract DA 44-177-TC-576, in laying the groundwork for design of certain aircraft recovery kit components proposed in this report. (Influence of the earlier work is reflected in some of the suspension system elements shown in Drawing SK10910, Sheet 1). Vertol analytic studies disclose, however, that additional devices are desirable or necessary to augment pitch, roll, and yaw stability of the recovered aircraft; the degree of necessity depending mainly on the aircraft type and the extent of damage or disassembly.

For compensating inherent pitch and roll instability of a damaged recovered aircraft, a practical solution is suspension of the "load" by a multiple cable system, deployed in both the lateral and longitudinal planes from the apex of the prime mover helicopter cargo sling. In special cases, one or more of these cables might not be required to support deadweight or vertical inertia load but would provide restraint against pitching or rolling perturbations.

Yaw stabilization of a load, such as a stripped H-21 fuselage, in forward cruise flight presents a more complex problem with a single point suspension cable system. This is likewise true in restraining the H-21 fuselage and other relatively large "flat plate" loads against rotation induced by rotor downwash swirl of the prime mover helicopter in hover or transition flight. Nevertheless, it is considered imperative to maintain a single-point connection between prime mover and load for maximum safety in the event that emergency jettisoning of the load is necessary. A solution to the yaw problem was sought with the single-point connection as a primary requirement.

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At the outset, two general types of solution appeared worthy of investigation:

(1) An aerodynamic stabilizing system consisting of trim-adjustable fins attached to the disabled aircraft (capable of compensating rotation effect of rotor downwash swirl of the prime mover helicopter in hover, as well as serving in lieu of damaged fin surfaces of the disabled aircraft in forward cruise flight);

(2) A mechanical system whereby directional moments of the disabled aircraft would be resisted through a single-point, torque-carrying linkage to the prime mover cargo sling.

Analytic and design studies of these two approaches were conducted in parallel. Typical systems of both types were evaluated as to functional efficiency and on the basis of economic and logistic factors. Results of these studies indicate that a composite system employing both aerodynamic and mechanical yaw restraint features will provide the best solution.

With respect to functional efficiency, the advantages of the aero-mechanical system are explained and graphically portrayed (Figure 8) in the section of this report entitled "Evaluation of Analog Computer Studies." Briefly, these advantages lie in the capability of the aero-mechanical system to provide positive yaw stabilization of the load throughout the speed range of practical interest (zero to 50 knots), without undue drain on available control power of the prime mover helicopter. Detracting from the purely mechanical yaw restraint system is its tendency to dictate different forward speed limits for each load characteristically different in yaw instability. Besides this, if speeds above 30 knots can be attained, the mechanical system may deprive the prime mover of a significant amount of control power.

An aerodynamic system with trim-adjustable fins has, in addition to functional deficiencies at transition flight speeds, some unattractive features of a logistical and economic nature. A trained crewman would be required in the cabin of the prime mover to "fly" the load; i.e., operate the trim-adjustment control of the fins throughout all flight regimes to maintain directional alignment of the load. Furthermore, an appreciable cost would be entailed in the development of inflatable airfoil-shape fins with remotely-controlled movable control surfaces. Opposed to this relatively complex device, the fins required for the composite aero-mechanical system would be simply flat panel inflatable

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bags with no hinged control surfaces. (In either case, the inflatable fin surface is a concept for a "production" version; functional testing could be performed with a prototype fin of lightweight rigid construction.)

It is not asserted that the aeromechanical yaw restraint system will be without development problems. One disadvantage is that it requires replacement of the standard helicopter external cargo hook with the special device shown in Drawing SK10910, Sheet 2. Also, actual testing will be necessary to establish whether theoretical spring rates employed in computer studies can be incorporated and retained within acceptable tolerances in practical "hardware." However, Vertol studies thus far indicate a clear-cut advantage in pursuing development of this aeromechanical system, by comparison with any other feasible method of providing similar functional capabilities.

The aeromechanical yaw restraint system is not required for all aircraft recovery operations. A synopsis of Army aircraft recovery cases (Tables XI and XII) and a set of illustrated charts (Drawings SK10911 through SK10921) are presented to indicate the recommended recovery system components and recovered aircraft configuration associated with each case. In selecting a spectrum of recovery cases for the design study, it is apparent that some practical limitations must be imposed. The possible variation of damage to the eleven different types of Army aircraft considered is virtually infinite. However, the following approach has been adopted for establishing a significant envelope of recovery cases, particularly to reflect analytic findings of the present study:

(1) The eleven Army aircraft types with which the study is concerned are each considered as recovered aircraft without significant aerodynamic or structural damage. They are dismantled as required to conform to lifting capacities of the respective prime mover helicopters. (H-21 and H-34, 3,000 lb; H-37, 6,900 lb)

(2) Additionally, the four fixed wing type aircraft and the H-21, H-34, and H-37 helicopters are each considered as recovered aircraft with specific instances of aerodynamic damage (such as to vertical tail or pylon, wing, horizontal tail, etc.).

The four smaller helicopters (H-13, H-23, HU-1A, and H-19), with aerodynamically damaged airframes, are not expected to create problems distinct from those encountered in aerial recovery of the intact helicopters (less rotor blades). Lifting capacities of the three prime

GENERAL

mover helicopters, as specified on the previous page, are determined from rational considerations of prime mover useful load requirements and rotor download on the recovered aircraft hull (Reference Table VII). In special instances (such as ambient conditions more favorable than the sea level standard conditions assumed for this analysis) greater loads could be lifted. However, lifting capacities applied in this report are stated on a common basis for the three prime movers. Military flight test data (References 19, 20, 36, and 37) are the source for minimum flying weight and maximum hovering gross weight capabilities of the H-21, H-34, and H-37. With these basic data, uniform procedures have been used in deriving maximum external cargo loads compatible with the military test data and with the special load parameters of the aircraft recovery mission. Thus, the assigned lifting capacities provide an equitable and realistic appraisal of aircraft recovery mission capabilities.

Preliminary design of the proposed recovery kit has been supported by stress analysis of principal components. Rational stress criteria were established for the load suspension system and for the recovery kit fin assembly. These are stated in Table XIII. Detail stress analysis is included in Appendix VII in Volume II of this report. Results of the analysis are summarized in Table XIV in Volume I. For simplicity, the main elements of the load suspension system have been analyzed for design loads associated with the greater vertical inertia and directional moment capacities of the H-37 prime mover. Detailed analysis of a design for fabrication might show a modest weight differential (possibly 20-30 pounds) between a suspension system tailored to H-37 loading capacities on the one hand and to H-21 and H-34 capacities on the other. However, preliminary analysis performed in this report indicates that a suspension system, including yaw restraint devices and adequate for all three prime movers, might be developed at a weight cost of no more than 150 pounds (for the maximum mission installation). It may therefore be determined that reducing the number of kit components by adopting a "universal" suspension system may override the advantage of a moderate weight saving in special, lighter weight devices for H-21 and H-34 systems.

PRELIMINARY DESIGN OF RECOVERY SYSTEM
LOGISTIC CONSIDERATIONS FOR DESIGN OF RECOVERY SYSTEM

The acceptance of a need for improved methods for crashed aircraft recovery is demonstrated from the available reports covering the recovery, or attempted recovery, of crashed aircraft by means of the helicopter.

An appraisal of equipment and methods used to date indicates that, although it has been shown that recovery by helicopter is feasible under certain conditions, it is readily apparent that the state of the art leaves much to be desired.

The evolution of an acceptable and practical recovery system can only be accomplished if a full understanding of what transpires from the time the aircraft crashed to the time the aircraft is returned to base for repair and overhaul.

With this in mind, a full appraisal of recovery operations recorded to date has been made. Existing reports on practical experience in recovery of crashed aircraft under all types of conditions have been analyzed.

This appraisal can be broken down as follows:

1. Appraisal of crash damage
2. Location of crash
3. Transportation of crash party and equipment
4. Preparation of crashed aircraft for recovery

1. Appraisal of Crash Damage

Full qualified appraisal must first be made to ascertain the condition of the crashed aircraft. This will determine the percentage of the crash worth recovering. Essentially, this appraisal will determine whether or not the main structural members are sufficiently sound to permit safe lifting and transporting of the damaged aircraft by helicopter.

The crash appraisal will provide information to the crash party on what equipment must be available to do the job efficiently.

2. Location of Crash

The crash location will have a distinct bearing on the type of equipment that will be needed and the techniques to be employed to effect a safe, successful recovery.

The nature of the terrain at the crash site is a variable. It may be marshland, wooded hills, steep gravel slopes, deep snow, frozen soil,

thick ice, etc. The equipment must be adaptable to all these conditions.

Temperature may range from -40°F to 140°F.

3. Transportation of Crash Party and Equipment

It is assumed that the equipment and crash party will be transported by helicopter to a location as near as practical to the crash site.

All equipment necessary to carry out specific crash recovery missions should be designed so that it can be easily stowed in the fuselage of the prime movers. Individual items of equipment should be of a size and weight that can be easily lifted by no more than two men.

4. Preparation of Crashed Aircraft

The parts to be removed from a crashed aircraft, in order to be lifted by a given prime mover, have been determined for each aircraft type. The appraising officer will check this prior to commencement of a specific operation. This knowledge will permit close approximation of the position of the crashed aircraft's center of gravity.

Equipment must include suitable means for removing these removable items. Provision must be made for transporting these items back to base. They should be suitably packed in order to prevent further damage during transit.

A portable gantry is recommended to assist in the removal of larger items of equipment. However, since the crash site may be mud, soft earth, snow or sloping, a gantry which rests on the ground may be unsuitable for a significant percentage of recovery operations. Since the only stable platform at the crash site is likely to be the crashed aircraft itself or the prime mover, a gantry should be designed that can be fitted to the crashed aircraft itself. Provision could be built into the aircraft structure for gantry installation, or a means similar to that shown on SK-10452 could be developed.

One of the principal requirements at the crash site will be to get the crashed aircraft into a normal attitude in order for the prime mover to lift and transport it back to base. Since the terrain conditions may be unsuitable for the use of a gantry, it is proposed that air inflated bags be considered for this operation. A simulated recovery using air inflated bags is shown on SK-10447. The use of air bags provides equipment that can be easily transported; they can be used on any type of ground, including water covered mud. They can be adapted to inclined crash sites. The use of bags ensures that no further

damage is done to the crashed aircraft during lifting, and with the use of guy lines, the crashed aircraft can easily and safely be held in its normal attitude awaiting pickup. The use of bags also ensures, when the crash is in mud or frozen into snow, that the crash is raised clear without the use of "snatching" or locally applied loads which may cause further damage.

Other "basic" equipment required to complement that already mentioned would be:

(1) A portable air compressor to inflate the lifting bags. This compressor could also be used for operating portable power tools, e.g., saws.

(2) Suitable axes and saws to clear any trees or brush from the crash site.

(3) Suitable top clothing for crash crew, e.g., long rubber boots for mud, water and snow.

(4) A portable heater, to place inside fuselage of crashed aircraft (in winter) with sufficient output to melt any snow and ice that may be on fuselage. This heater will also provide some measure of comfort to the crash party.

(5) Suitable cargo nets will be required to transport parts dismantled from the crashed aircraft. Large plastic bags should also be included to protect these removed parts.

The above would form the "basic" kit and would be packaged and stored at base. The packages will be of a size and weight that will facilitate easy handling and stowage inside the helicopter.

5. Communication

Subsequent to preparation of the disabled aircraft the prime mover must accomplish the "hook-up" operation. During this operation the pilot is unable to observe the "hook-up" or the exact position of the hook with respect to the load. If the prime mover hook is not properly centered over the center of gravity of the load when the "pickup" is attempted, there is a possibility that roll or pitch moments developed will be sufficient to exceed the control limits of the prime mover. The eccentricity that falls within the control power limitation of the prime mover is a function of the external load weight and the distance between the prime mover hook and the cg of the load. The effects of these two

parameters on the acceptable lateral essectric lifting capabilities of the H-21 prime mover are depicted in Figures 9 and 10. The H-34 will have slightly greater lateral and longitudinal tolerances than the H-21 lateral limits. The H-21 longitudinal control power limit is much less critical due to the tandem rotor configuration. In addition to the essentric lifting consideration there exists the requirement for pilot cognizance of difficulties encountered during the "hook-up" that warrants aborting the "pickup" attempt. The historical review cited a case where the pilot interpreted a ground crewman's hand signal as "go around, missed hook-up" instead of the "load secured" meaning that the signal was intended to convey.

The requirement for adequate intercommunication between the pilot and the ground crew can be fulfilled by the following two proposed approaches.

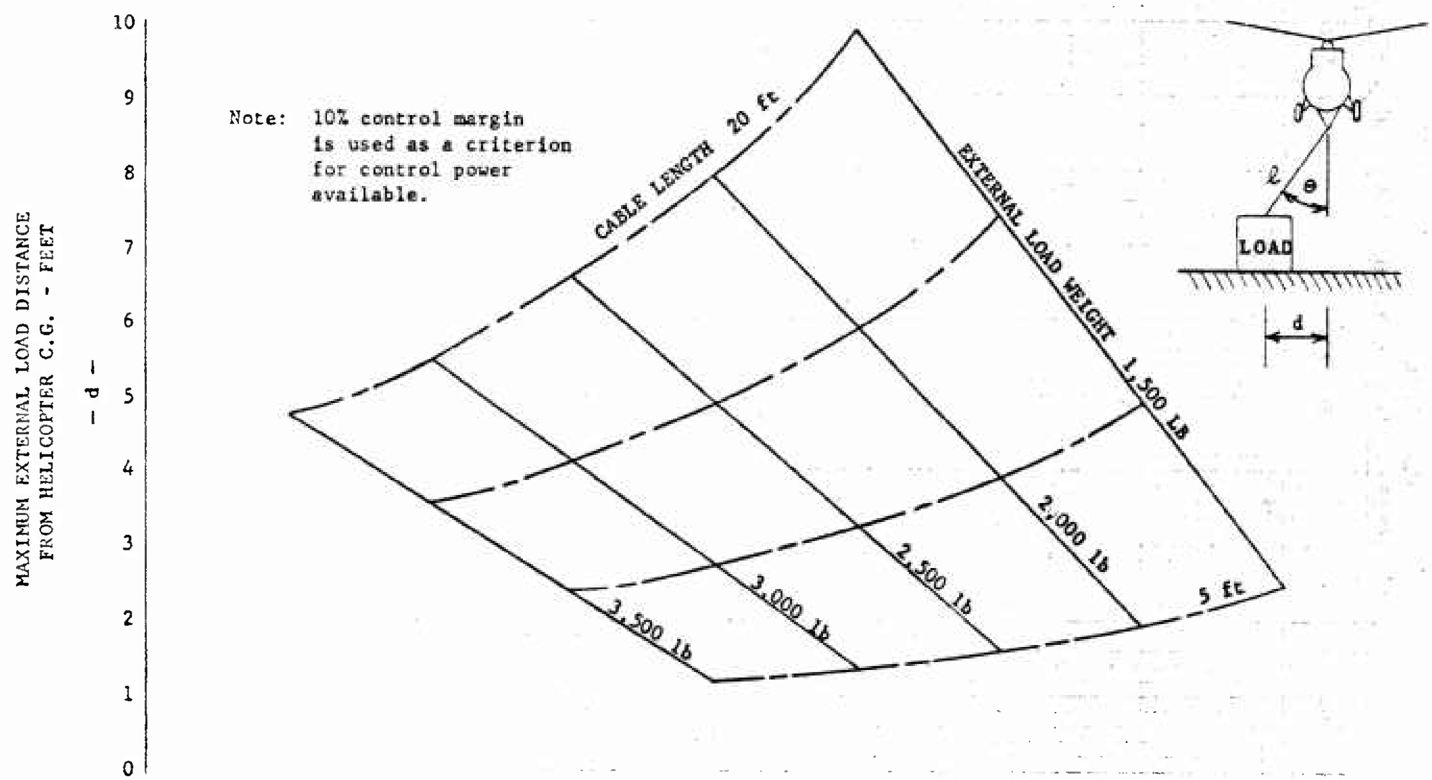
1. A drill be developed similar to the L.S.O. technique used by the Navy for carrier landing of aircraft.

2. An infrared communication system. This type of system has already reached a reliable state. It is free from electrical interference and it does not rely on prime mover to ground connection. Sets are on the market at very low price which could be used to qualify this proposed method, thereby eliminating any initial development costs.

FIGURE 9

VERTOL H-21 EXTERNAL LOAD LATERAL DISPLACEMENT STUDY

G.W. 14,350 lb   RPM 258   Alt. S.L.   Std. Day   Hover



PLOT IS FOR G.W. = 14,350 lb

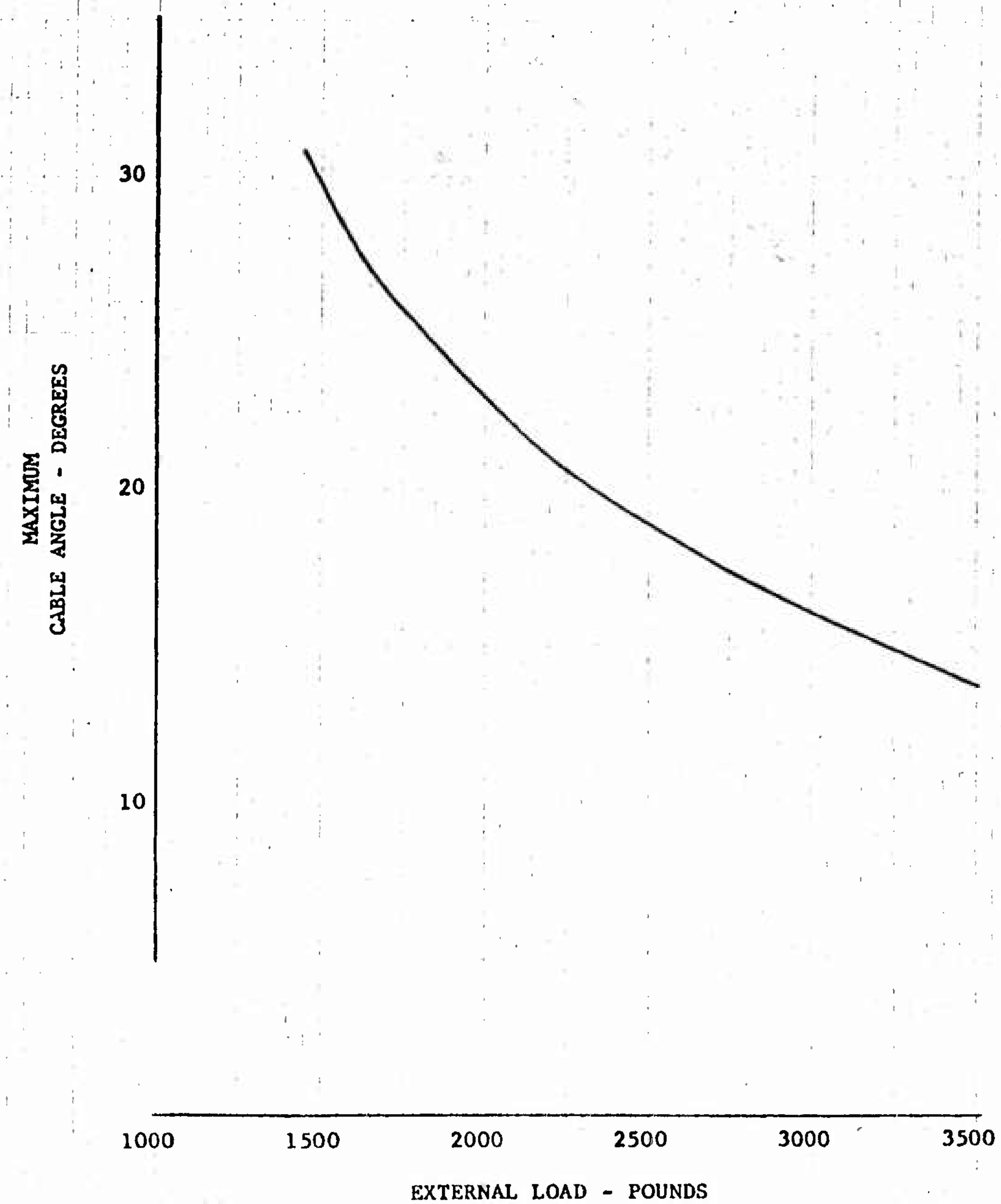
FOR d DUE TO Δ G.W. $\quad d \approx \frac{G.W.}{14,350}$

FIGURE 10

VERTOL H-21 EXTERNAL LOAD LATERAL CABLE ANGLE STUDY

G.W. 14,350 lb RPM 258 Alt. S.L.

Std. Day Hover



DESIGN CONCEPT FOR AIRCRAFT RECOVERY SYSTEM (SUSPENSION AND RESTRAINT OF RECOVERED AIRCRAFT)

The engineering sketches and charts following this discussion are a graphic presentation of the devices and techniques for aerial aircraft recovery evolved in this study. Three of these drawings are design layouts of the devices proposed for in-flight suspension and restraint of the recovered aircraft "load":

SK10910 - (Sheet 1) Kit Components, Aircraft Recovery System Suspension Components and Mat

SK10910 - (Sheet 2) Yaw Restraint Connection

SK10910 - (Sheet 3) Stabilizing Fin Kit

Drawing SK10910, Sheet 1, consists mainly of "standard hardware" corresponding generally to recovery kit components proposed by the Nems Clarke Company under Contract DA44-177-TC-576. This includes wire rope assemblies, nylon strap assemblies, shackles, adapters, etc. A nylon rope mat is also included to provide means for protecting the recovered aircraft hull from suspension hardware dropped at load release.

On Sheet 2 of Drawing SK10910 is shown the detail of the load-rotation restraint and hook-up system. In this system the tendency of the load to rotate due to rotor downwash is opposed by the supporting cables. Cable-spreader torque plates are designed to introduce a pre-determined mechanical spring rate to counteract rotational moment applied to the load by downwash swirl of the prime mover helicopter rotor in hovering and transition flight (approximately 0 to 30 knots). Hinges in the joint between upper and lower torque plates prevent pitch and roll moments of the recovered aircraft from being transferred to the prime mover. A one-point mechanical release is provided which can be actuated by the ground crew or by the flight crew in the prime mover helicopter.

This mechanical yaw restraint system is designed for use with all three prime movers and a wide variety of recovered aircraft load configurations. Strength is provided for the greatest inertia forces and yawing (torsional) moments anticipated from any recovery loads within the capacity of each of the three prime movers. Further, variable-position attachment of cables is provided on the hinge-connected upper and lower torque plates. In effect, this provides "center of gravity control" of the load. Proper selection of cable attach-

DESIGN CONCEPT FOR AIRCRAFT RECOVERY SYSTEM (SUSPENSION AND RESTRAINT OF RECOVERED AIRCRAFT)

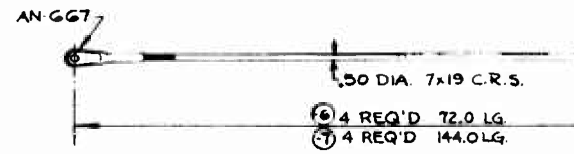
ment points will level the load and torque plates in the static, free-suspension condition of the load for a wide spectrum of load cg positions and cable configurations. If perturbations accelerate the load about the pitch and/or roll hinge, the torque plates will be tilted in conformance with kinematic motion of the suspension system. Kinematic studies indicate that plate tilting will not exceed ±20 degrees, with load vector "coning" up to 60 degrees apex angle. However, a development effort is required to assure that kinematic motions of the system do not create problems, such as jamming of the load release mechanism or interference of the upper and lower torque plates. In respect to the latter consideration, an adjustment (for development testing) is provided in the length of the "neck" between the two torque plates, as shown in SK10910, Sheet 2.

Drawing SK10910, Sheet 3, illustrates the proposed aerodynamic yaw-stabilizing device for the load in forward flight. This is a functional test kit comprised of segmented flat panel, honeycomb core construction fin surfaces, designed to be mounted to the fuselage of a damaged aircraft by tubular struts, guy wires, and nylon web straps. The amount of fin area can be altered in accordance with requirements of the recovered aircraft by the number of fin panel segments installed. The position of these fins is adjustable on the ground but not in flight. However, the fins, acting in combination with the mechanical spring described above, provide a load yaw-stabilizing system that should be effective throughout the complete flight regime of practical interest; that is, from zero to fifty knots. In development of a field service kit, consideration should be given to inflatable-type flat panel fins, since these may offer advantages in compactness for stowage.

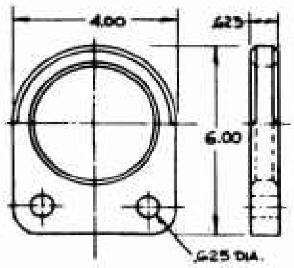
Following the three-page gatefold Drawing SK10910 are tabulations (Tables XI and XIII) identifying by word description and code symbols the various aircraft recovery cases considered in this report. As indicated in the general discussion earlier in this preliminary design section, the spectrum of recovery cases was established with practical limitations of scope but with view to fully representing the results of the present study. Illustrations of the application of the SK10910 recovery kit, or parts thereof, to pertinent aircraft recovery operations are presented in Drawings SK10911 through SK10921, following Table XII. Each of the eleven drawings deals with a particular recovered aircraft type in combination with H-21, H-34, and H-37 prime movers. Also included on each of these drawings are charts showing stripping requirements of the recovered aircraft and recovery kit items needed for the missions illustrated.

WIRE ROPE ASSEMBLY

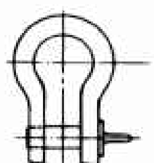
QUAN.	PART NO.	L	D	W	T	d
4	-4	72	.50	.413	.468	.625
2	-5	180	.50	.413	.468	.625



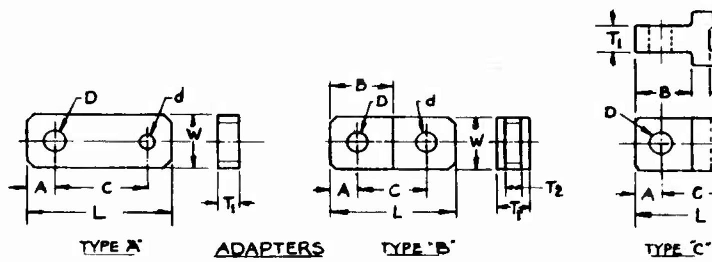
WIRE ROPE ASSEMBLY



-8 HOOK ADAPTER
2 REQ'D



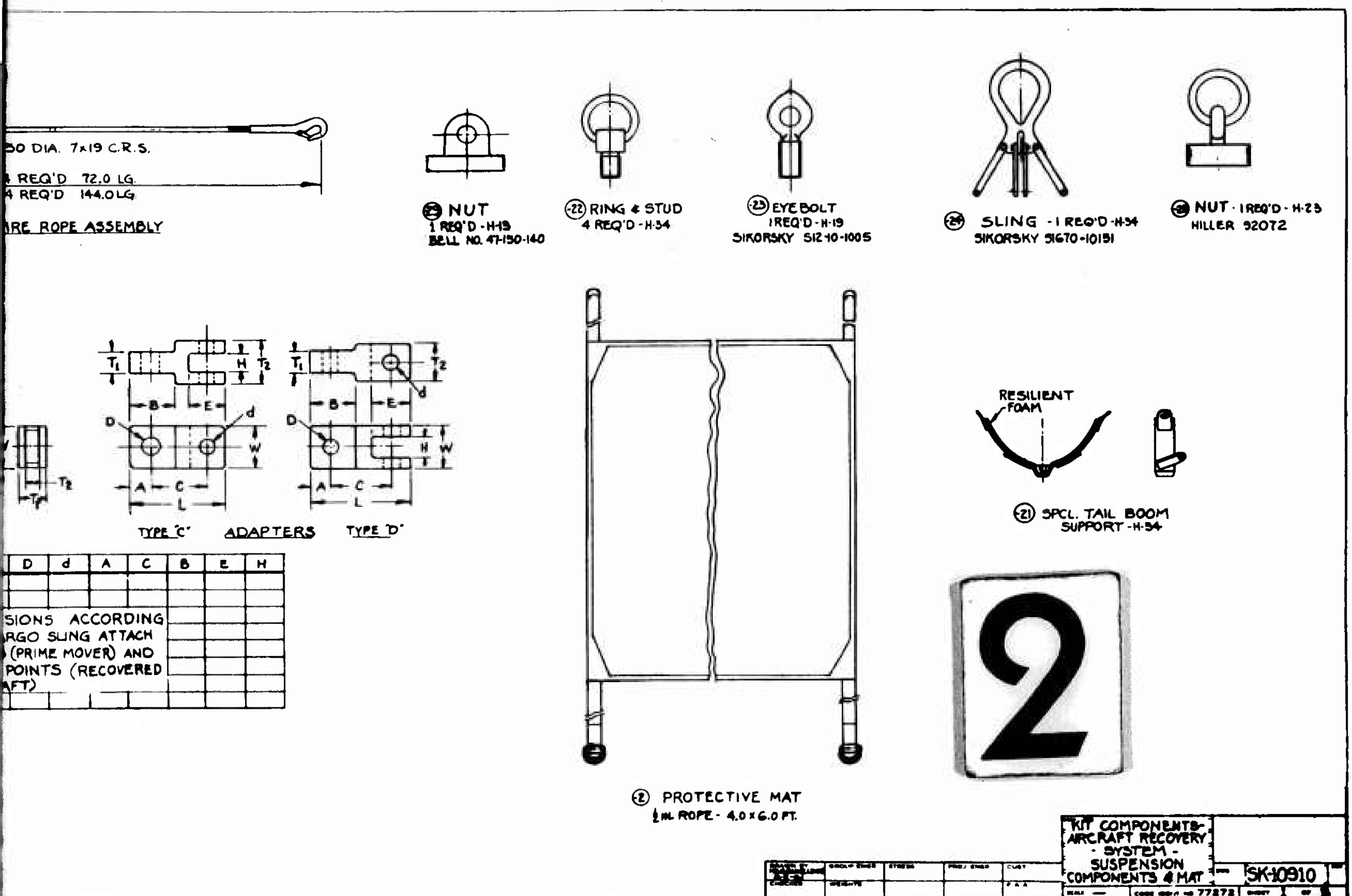
SHACKLES
-26 (2) AN-116-6
-27 (4) AN-116-8
-28 (2) AN-116-12



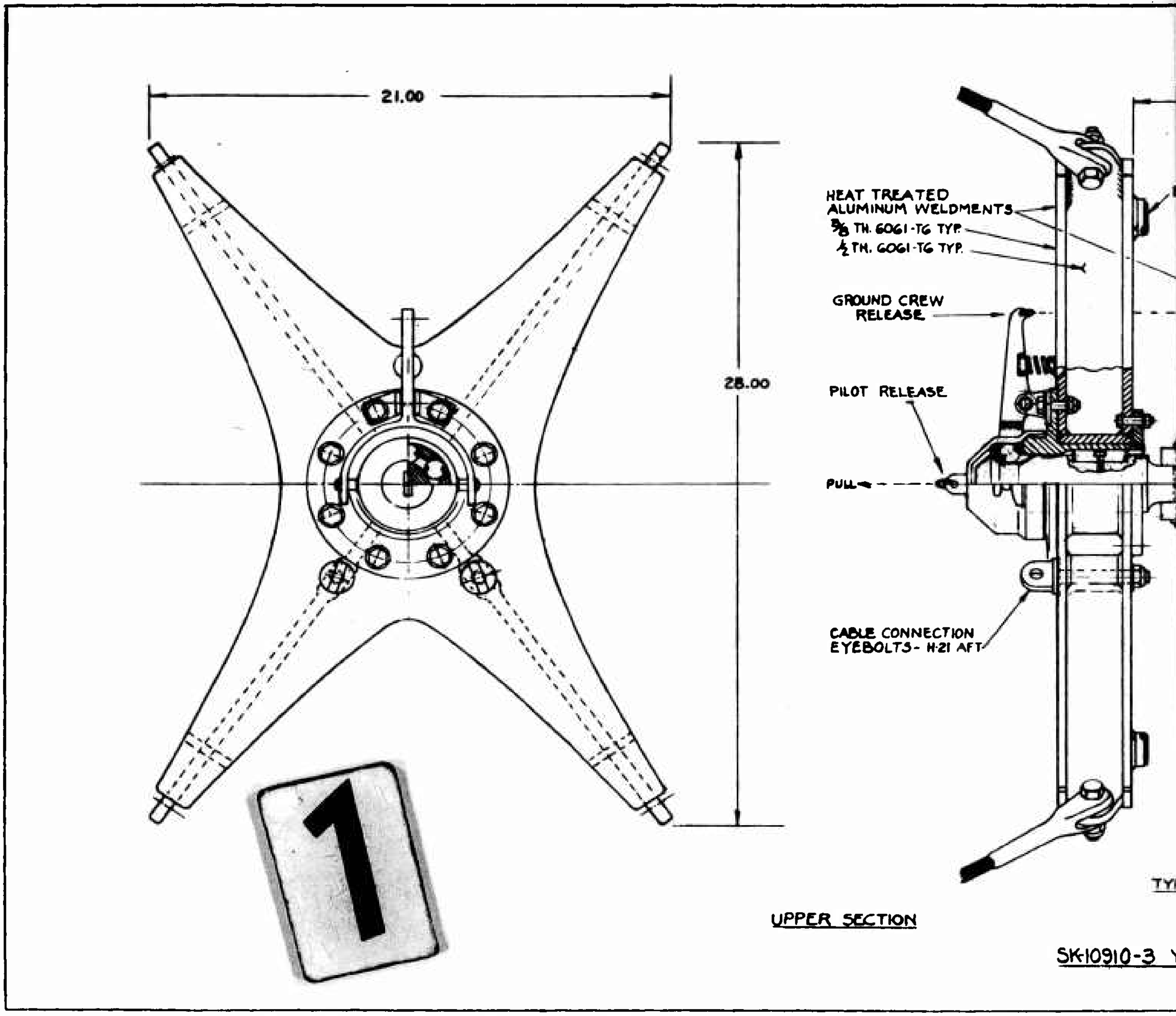
ADAPTERS

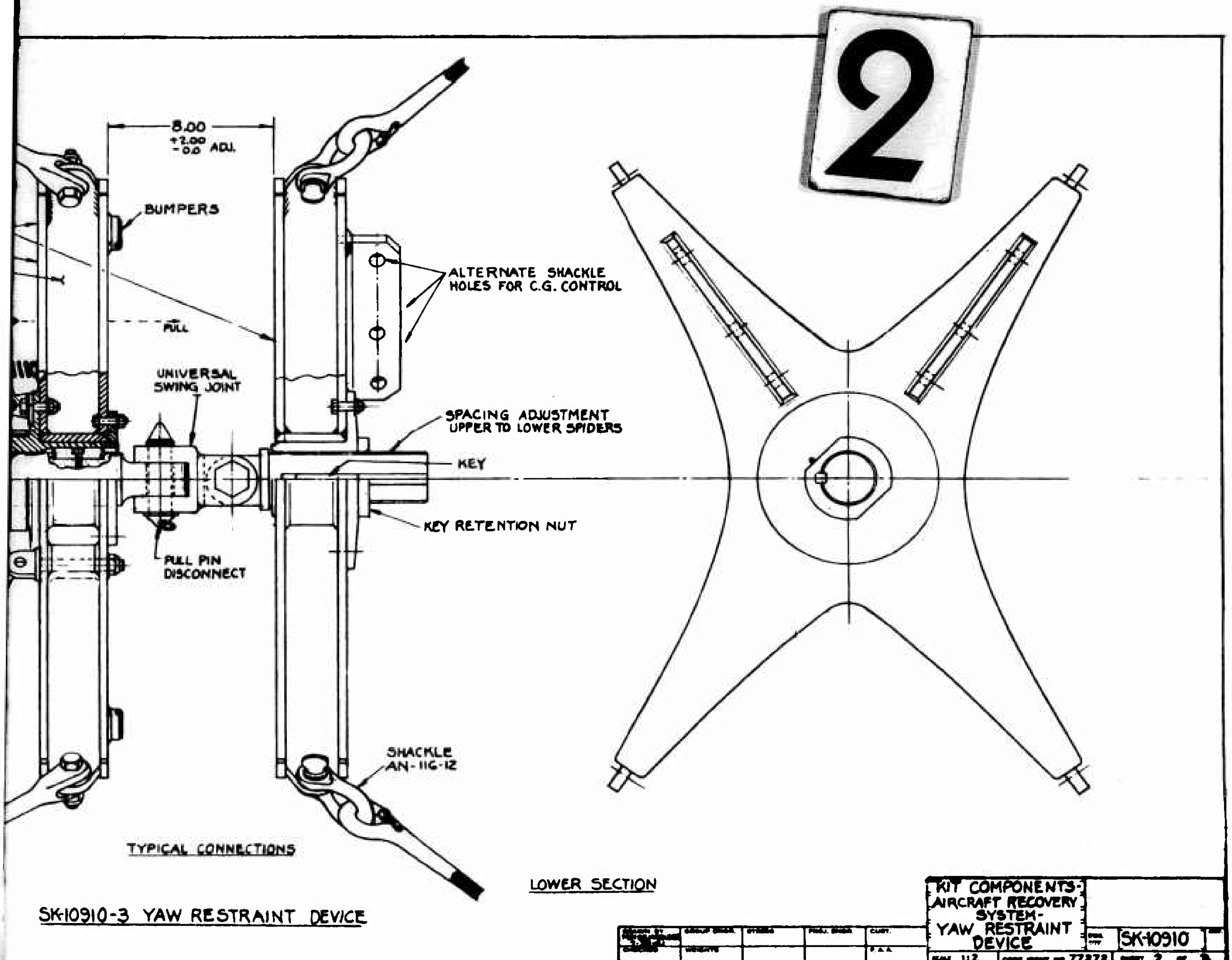
QUAN.	-NO.	TYPE	L	W	T_1	T_2	D	d	A	C	B
	-11	A									
	-12										
	-13	B			DIMENSIONS ACCORDING TO CARGO SLING ATTACH POINTS (PRIME MOVER) AND HOIST POINTS (RECOVERED AIRCRAFT)						
	-14										
	-15	C									
	-16										
	-17	D									
	-18										

NYLON WEB STRAP ASSEM.
-9 6 REQ'D - 16 FT. MAX.
-10 1 REQ'D - 8 FT. MAX.

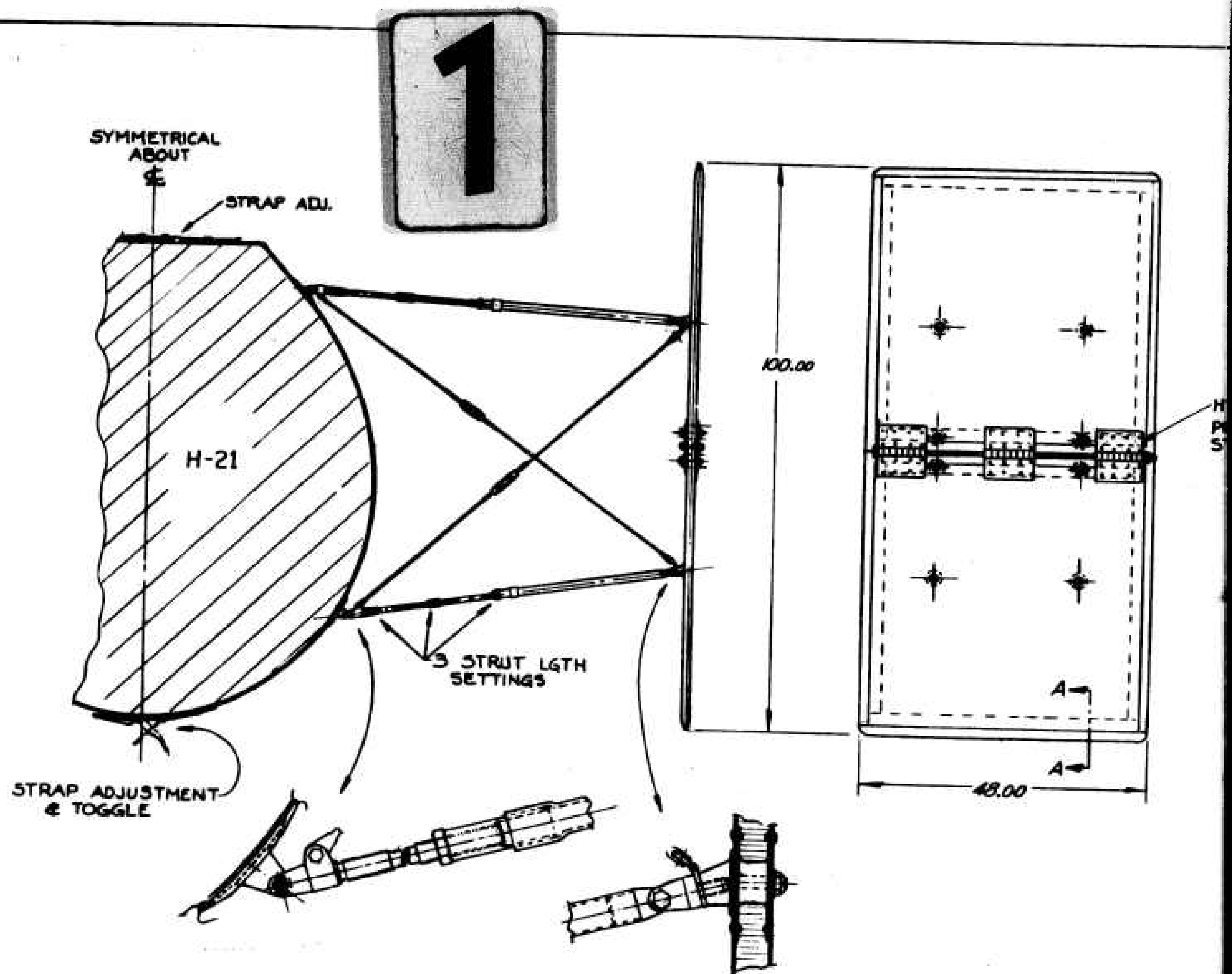


50 DIA. 7x19 C.R.S.
REQ'D 72.0 LG.
4 REQ'D 144.0 LG.
RE ROPE ASSEMBLY
NUT
1 REQ'D - H-19
BELL NO. 47-150-140
(22) RING & STUD
4 REQ'D - H-34
(23) EYE BOLT
1 REQ'D - H-19
SIKORSKY S1210-1005
(24) SLING - 1 REQ'D - H-34
SIKORSKY S1670-10151
NUT - 1 REQ'D - H-23
HILLER 52072
TYPE "C"
ADAPTERS
TYPE "D"
D d A C B E H
SIONS ACCORDING
RGO SLING ATTACH
(PRIME MOVER) AND
POINTS (RECOVERED
AFT)
RESILIENT
FOAM
(21) SPCL. TAIL BOOM
SUPPORT - H-34
(2) PROTECTIVE MAT
½ IN. ROPE - 4.0 x 6.0 FT.
2
KIT COMPONENTS-
AIRCRAFT RECOVERY
- SYSTEM -
SUSPENSION
COMPONENTS & MAT
SK-10910
77272


21.00
28.00
HEAT TREATED ALUMINUM WELDMENTS
3/8 TH. 6061-T6 TYP.
1/2 TH. 6061-T6 TYP.
GROUND CREW RELEASE
PILOT RELEASE
PULL
CABLE CONNECTION EYEBOLTS- H-21 AFT
TYP
UPPER SECTION
SK-10910-3 Y
1

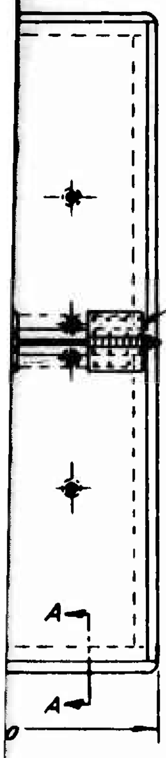


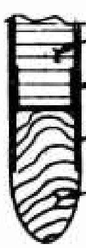
2
8.00
+2.00
-0.0 ADJ.
BUMPERS
ALTERNATE SHACKLE HOLES FOR C.G. CONTROL
FULL
UNIVERSAL SWING JOINT
SPACING ADJUSTMENT UPPER TO LOWER SPIDERS
KEY
KEY RETENTION NUT
PULL PIN DISCONNECT
SHACKLE AN-11G-12
TYPICAL CONNECTIONS
LOWER SECTION
SK-10910-3 YAW RESTRAINT DEVICE
KIT COMPONENTS-AIRCRAFT RECOVERY SYSTEM-YAW RESTRAINT DEVICE
SK-10910
1:2
77272
2



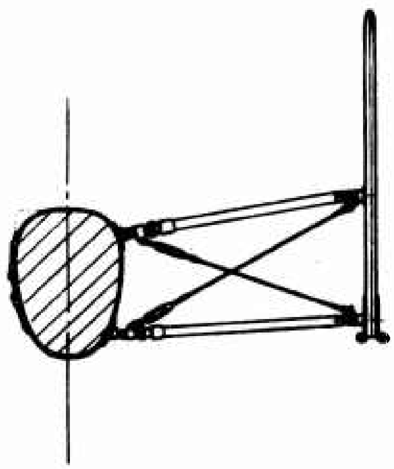
TYPICAL INSTALLATION
TWO FULL FINS ON LARGE CROSS SECTION FUSELAGE

SK-10910-30 STABILIZER FIN





SECTION 'A-A'
TYPICAL EDGE



TYPICAL INSTALLATION
SINGLE HALF FIN ON SMALL
CROSS SECTION FUSELAGE

2

O STABILIZER FIN KIT

KIT COMPONENTS-
AIRCRAFT RECOVERY
SYSTEM -
STABILIZER FIN
KIT

SK-10910

CODE IDENT. NO. 77272

SHEET 3 OF 3

TABLE XI INDEX FOR SYMBOL CODE APPLIED TO AIRCRAFT RECOVERY CASES

Code	Recovered Aircraft	Code	Prime Mover	Code	Recovery Configuration of Recovered Aircraft
I	H-13	A	H-21	1.	Basic Aircraft Intact
II	H-23	B	H-34	2.	No Aerodynamic Damage; Stripped for Weight and Balance Only.
III	HU-1A	C	H-37		
IV	H-19			3.	Basic Aircraft Less Main and Tail Rotor Blades.
V	H-34				
VI	H-21			4.	Damaged Vertical Tail or Pylon.
VII	H-37			5.	Damaged Horizontal Stabilizer and/or Wing.
VIII	L-19				
IX	L-20			6.	Aft cg; Damaged Engine(s) Removed
X	L-23				
XI	U-1A				

Example: If an L-19 that has been damaged to the degree that the wings must be removed, is to be recovered by an H-21 Prime Mover, the recovery operation code designation would be: VIII-A-5.

TABLE XII

SUMMARY LIST OF AIRCRAFT RECOVERY CASES

Case Number	Recovered A/C and Chart Ref. Number	Prime Mover	Recovery Configuration of Recovered Aircraft	Remarks
I-A-3	H-13	H-21	Basic A/C, Less Main and Tail Rotor Blades (Wt: 1,360 lb)	No Yaw Restraint Devices Required
I-B-3	SK10911	H-34	Same	
I-C-3		H-34	Same	
II-A-3	H-23	H-21	Basic A/C Less Main and Tail Rotor Blades (Wt: 1,611 lb)	No Yaw Restraint Devices Required
II-B-3	SK10912	H-34	Same	
II-C-3		H-37	Same	
III-A-2	HU-1A	H-21	Stripped to 2,950 lb	No Yaw Restraint Devices Required
III-B-2	SK10913	H-34	Stripped to 2,950 lb	
III-C-3		H-37	Basic A/C Less Main and Tail Rotor Blades (Wt: 3,574 lb)	
IV-A-2	H-19	H-21	Stripped to 2,902 lb	No Yaw Restraint Devices Required
IV-B-2	SK10914	H-34	Stripped to 2,902 lb	
IV-C-3		H-37	Basic A/C Less Main and Tail Rotor Blades (Wt: 5,189 lb)	
V-A-2	H-34	H-21	Stripped to 2,998 lb	No Yaw Restraint Devices Required (Aeromechanical Yaw Restraint System Desirable to Increase Stability Margin)
V-B-2	SK10915	H-34	Stripped to 2,998 lb	
V-C-2		H-37	Stripped to 6,840 lb	
V-A-4	H-34	H-21		
V-B-4	SK10915	H-34		
V-C-4		H-37		
VI-A-2	H-21	H-21	Stripped to 3,000 lb	Install Aeromechanical Yaw Restraint System (Even when basic A/C tail assembly is intact)
VI-B-2	SK10916	H-34	Stripped to 3,000 lb	
VI-C-2		H-37	Stripped to 6,803 lb	

TABLE XII

SUMMARY LIST OF AIRCRAFT RECOVERY CASES, Continued

Case Number	Recovered A/C and Chart Ref. Number	Prime Mover	Recovery Configuration of Recovered Aircraft	Remarks
IX-A-4	L-20	H-21	Stripped to 2,727 lb (Remove Wing and Vertical Tail)	Install Aerodynamic Yaw Restraint System (Fin Kit); Control Locks Recommended; Wing Spoilers Recommended for IX-A and IX-B.
IX-B-4	SK10919	H-34	Same	
IX-C-4		H-37	Basic A/C Less Vertical Tail (Wt: 3,175 lb)	
IX-A-5	L-20	H-21	Stripped to 2,654 lb (Remove Wing and Stabilizer)	No Yaw Restraint Devices Required; Control Locks Recommended
IX-B-5	SK10919	H-34	Same	
IX-C-5		H-37	Same	
IX-A-6	L-20	H-21	Basic A/C Less Engine Aft cg (Wt: 2,323 lb)	No Yaw Restraint Devices Required; Wing Spoilers and Control Locks Recommended
IX-B-6	SK10919	H-34	Same	
IX-C-6		H-37	Same	
X-A-2	L-23	H-21	Stripped to 2,629 lb Remove Engine Group Assembly	No Yaw Restraint Devices Required; Wing Spoilers and Control Locks Recommended
X-B-2	SK10920	H-34	Same	
X-C-1		H-37	Basic A/C Intact (Wt: 3,995 lb)	
X-A-4	L-23	H-21	Stripped to 2,582 lb Remove Engine Group and Vertical Tail	Install Aerodynamic Yaw Restraint System (Fin Kit); Wing Spoilers and Control Locks Recommended
X-B-4	SK10920	H-34	Same	
X-C-4		H-37	Basic A/C Less Vertical Tail (Wt: 4,059 lb)	
X-A-5	L-23	H-21	Stripped to 2,311 lb or 2,210 lb (Remove Engine Group, Stabilizer and/or Wing Outer Panels)	No Yaw Restraint Devices Required; Control Locks Recommended
X-B-5	SK10920	H-34	Same	
X-C-5		H-37	Basic A/C Less Stabilizer and/or Wing Outer Panels (Wt: 3,577 lb or Wt: 3,476 lb)	
X-A-6	L-23	H-21	Basic A/C Less Engine Group Aft cg (Wt: 2,629 lb)	No Yaw Restraint Devices Required; Wing Spoilers and Control Locks Recommended
X-B-6	SK10920	H-34	Same	
X-C-6		H-37	Same	

TABLE XII

SUMMARY LIST OF AIRCRAFT RECOVERY CASES, Continued

Case Number	Recovered A/C and Chart Ref. Number	Prime Mover	Recovery Configuration of Recovered Aircraft	Remarks
VI-A-4	H-21	H-21	Stripped to 2,838 lb	Install Aeromechanical Yaw Restraint System
VI-B-4	SK10916	H-34	Stripped to 2,838 lb	
VI-C-4		H-37	Stripped to 6,803 lb	
VII-A-Not possible	H-37	H-21	Stripped Hull Weight Exceeds Capabilities of H-21 and H-34 Prime Movers	Install Aeromechanical Yaw Restraint System
VII-B-Not possible	SK10917	H-34		
VII-C-2		H-37	Stripped to 6,921 lb	
VIII-A-1	L-19	H-21	Basic A/C Intact (Wt: 1,700 lb)	No Yaw Restraint Devices Required; Wing Spoilers and Control Locks Recommended
VIII-B-1	SK10918	H-34	Same	
VIII-C-1		H-37	Same	
VIII-A-4	L-19	H-21	Basic A/C Less Vertical Tail (Wt: 1,705 lb)	Install Aerodynamic Yaw Restraint (Fin Kit); Wing Spoilers and Control Locks Recommended
VIII-B-4	SK10918	H-34	Same	
VIII-C-4		H-37	Same	
VIII-A-5	L-19	H-21	Basic A/C Less Stabilizer and/or Wing (Wt: Less Wing & Stab.: 1,411 lb) (Wt: Less Wing: 1,661 lb)	No Yaw Restraint Devices Required; Control Locks Recommended
VIII-B-5	SK10918	H-34	Same	
VIII-C-5		H-37	Same	
VIII-A-6	L-19	H-21	Basic A/C Less Engine Group (Wt: 1,166 lb)	No Yaw Restraint Devices Required; Wing Spoilers and Control Locks Recommended
VIII-B-6	SK10918	H-34	Same	
VIII-C-6		H-37	Same	
IX-A-2	L-20	H-21	Stripped to 2,718 lb (Remove Wing Only)	No Yaw Restraint Devices Required; Control Locks Recommended, Wing Spoilers Recommended for IX-C
IX-B-2	SK10919	H-34	Same	
IX-C-1		H-37	Basic A/C Intact (Wt: 3,202 lb)	

TABLE XII

SUMMARY LIST OF AIRCRAFT RECOVERY, Continued

Case Number	Recovered A/C and Chart Ref. Number	Prime Mover	Recovery Configuration of Recovered Aircraft	Remarks
XI-A-2	U-1A	H-21	Stripped to 2,759 lb	Install Mechanical Spring Yaw Restraint System; Wing Spoilers and Control Locks Recommended
XI-B-2	SK10921	H-34	Same	
XI-C-1		H-37	Basic A/C (Remove Propeller and Stow in Cabin for Ballast)(Wt: 4,848 lb)	
XI-A-4	U-1A	H-21	Stripped to 2,859 lb	Install Aeromechanical Yaw Restraint System; Wing Spoilers and Control Locks Recommended
XI-B-4	SK	H-34	Stripped to 2,859 lb	
XI-C-4		H-37	Basic A/C Less Vertical Tail (Remove Propeller and Stow in Cabin for Ballast) (Wt: 4,871 lb)	
XI-A-5	U-1A	H-21	Strip to lb	Install Mechanical Spring Yaw Restraint System; Control Locks Recommended
XI-B-5	SK	H-34	Same	
XI-C-5		H-37	Basic A/C Less Stabilizer and/or Wing (Remove Propeller and Stow in Cabin for Ballast) (Wt: less wing: 4,080 lb) (Wt: less wing & stab.: 3,951 lb)	
XI-A-6	U-1A	H-21	Stripped to 2,759 lb (Aft cg)	Install Mechanical Spring Yaw Restraint System; Wing Spoilers and Control Lock Recommended
XI-B-6	SK	H-34	Same	
XI-C-6		H-37	Stripped to 3,644 lb(Aft cg)	

LIST OF AIRCRAFT RECOVERY CASES, Continued

NOTES:

1. Recovered aircraft are considered to retain structural integrity for lifting at standard hoisting points.

2. Landing gears are included in all recovered aircraft weights. Defaltion and locking of oleo struts may be desirable to provide firm ground contact indication to the pilot upon load release.

3. Horizontal tails must be intact on all fixed wing recovered aircraft when wing is left on for aerial evacuation.

4. Wing panels removed from fixed wing type recovered aircraft should not be strapped to fuselage sides for aerial evacuation.

5. Propeller removal is optional on fixed wing type recovered aircraft except where otherwise indicated in the chart.

6. Recovery Kit requirements for combinations of specific cases of damage shown in the chart will include all devices required for any of the individual types of damage incurred.

7. The "aeromechanical" yaw restraint system includes both the strap-on fin kit assembly and the mechanical spring devices in the load suspension system.

RECOVERED AIRCRAFT WEIGHT STRIPPING LIST H-13
WEIGHT EMPTY-1,546 LB. C.G. LOCATION-87 132,920

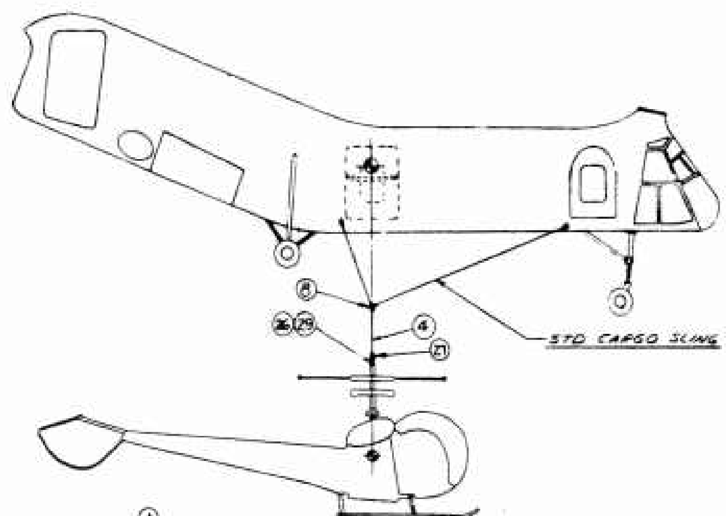
ITEM	GROUP	WEIGHT	ARM	MOMENT	RECOVERY AIRCRAFT H-21	H-34	H-37
1	ROTOR BLADES - MAIN (OR FWD)	180	85	15,300	X	X	X
2	ROTOR BLADES - TAIL (OR AFT)	6	335	2,010	X	X	X
3	ENGINE	402	85	34,170			
4	ENGINE OIL COOLER	17	70	1,190			
5	OIL TANK						
6	FUEL TANK	26	110	2,860			
7	TRANSMISSION OIL COOLER						
8	TRANSMISSION - FWD						
9	TRANSMISSION - AFT	259	85	22,015			
10	TRANSMISSION - CENTER						
11	CLUTCH MOTOR & PUMP						
12	MAIN DRIVE SHAFT						
13	ROTOR BRAKE						
14	TRAPPED FUEL & OIL	8	90	720			
15	TAIL ROTOR DRIVE SHAFT						
16	TAIL ROTOR PYLON	24	315	7,560			
17	TAIL CONE OR BOOM	63	210	13,230			
18	COCKPIT	44	40	1,760			
19	CABIN						
20	ELECTRONICS	97	15	1,455			
21	HEATER						
22	WING						
23	STABILIZER						
24	RUDDER						
25	LANDING GEAR	66	70	4,620			
26	ENGINE COMPARTMENT DOORS						
27	MISCELLANEOUS						
28							
29							
30	KIT STABILIZER						

	H-21	H-34	H-37
RECOVERY WEIGHT	1,360	1,360	1,360
C.G.	85	85	85
NO. OF TRIPS (MAX)	1	1	1

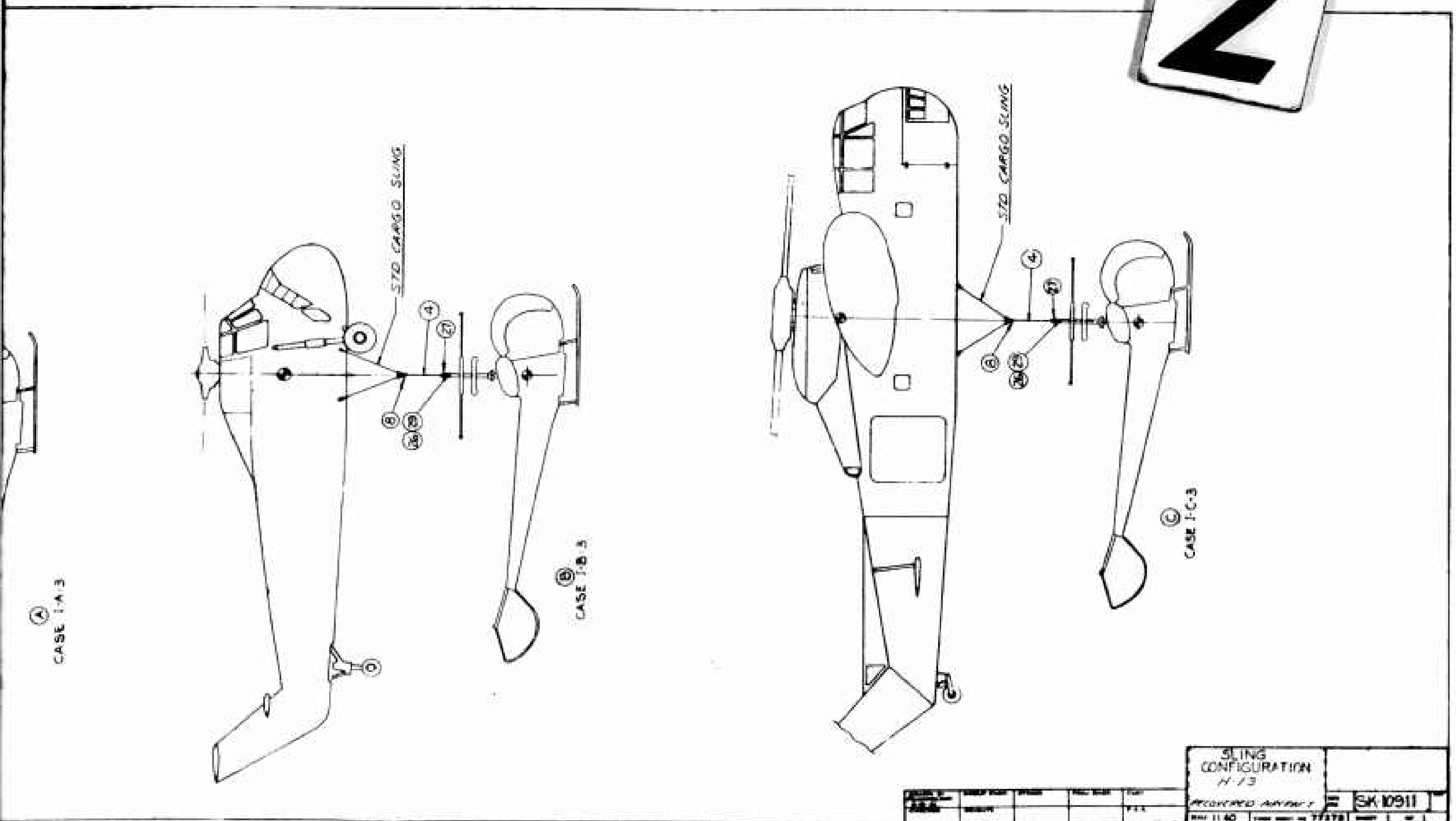
KIT REQUIREMENTS

ITEM	NAME	PART NO.	WT. EACH	TOTAL REQ'D	QUANTITY REQUIRED H-21	H-34	H-37
1	STD CARGO SLING*			1	1	1	1
2	PROTECTIVE MAT			1	–	–	–
3	YAW RESTR. CONN.			1	–	–	–
4	WIRE ROPE ASSEM.	SK10910-4		1	1	1	1
5							
6							
7							
8	HOOK ADAPTER	SK-10910-8		1	1	1	1
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							
25							
26	SHACKLE	AN-116-5		1	1	1	1
27	SHACKLE	AN-116-8		1	1	1	1
28							
29	NUT	BELL-47-150-140		1	1	1	1
30							
31							
32							
33							
34							

*AIRCRAFT EQUIPMENT-NOT PART OF KIT



(A)
CASE I-A-3


STD CARGO SLING
STD CARGO SLING
CASE I-A-3
CASE I-B-3
CASE I-C-3
SLING CONFIGURATION
H-13
SK 10911

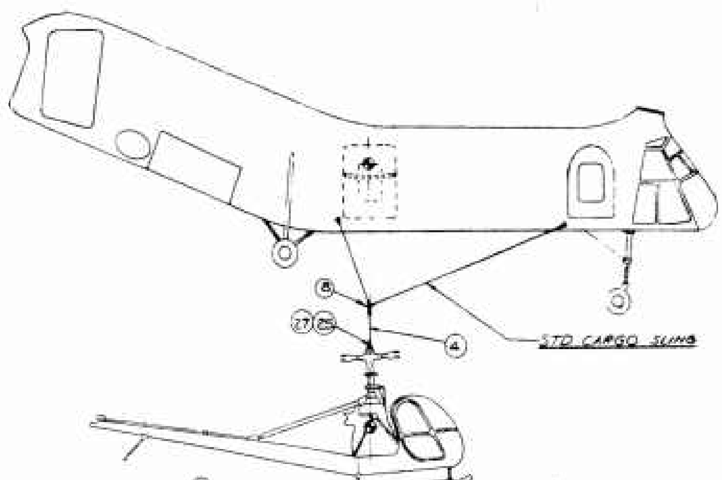
ITEM	RECOVERED AIRCRAFT WEIGHT STRIPPING LIST H-23 WEIGHT EMPTY-1828.5 LB. C.G. LOCATION-87.9 / 160,725 GROUP	WEIGHT	ARM	MOMENT	RECOVERY AIRCRAFT H-21	H-34	H-37
1	ROTOR BLADES - MAIN (OR FWD)	157.6	84	13,269	X	X	X
2	ROTOR BLADES - TAIL (OR AFT)	60	264	15,878	X	X	X
3	ENGINE	433.3	85.7	37,135.6			
4	ENGINE OIL COOLER						
5	OIL TANK (LUBRICATING SYSTEM)	20.9	94.1	1,966.7			
6	FUEL TANK (FUEL SYSTEM)	18.4	83.3	1,532.7			
7	TRANSMISSION OIL COOLER	20	84	1,680			
8	TRANSMISSION - FWD						
9	TRANSMISSION - AFT						
10	TRANSMISSION - CENTER	127.3	85	10,820.4			
11	CLUTCH MOTOR & PUMP	N/A					
12	MAIN DRIVE SHAFT	7.4	65	481.7			
13	ROTOR BRAKE	N/A					
14	TRAPPED FUEL & OIL						
15	TAIL ROTOR DRIVE SHAFT						
16	TAIL ROTOR PYLON						
17	TAIL CONE OR BOOM	68	174	11,832			
18	COCKPIT	100	71	7,100			
19	CABIN						
20	ELECTRONICS	107	76	8,150.6			
21	HEATER						
22	WING	N/A					
23	STABILIZER	4.2	329	1,381.8			
24	RUDDER						
25	LANDING GEAR	87.6	73	6,401			
26	ENGINE COMPARTMENT DOORS						
27	MISCELLANEOUS						
28							
29							
30	KIT STABILIZER						

	H-21	H-34	H-37
RECOVERY WEIGHT	1,610.8	1,610.8	1,610.8
C.G.	81.68	81.68	81.68
NO. OF TRIPS (MAX)	1	1	1

KIT REQUIREMENTS

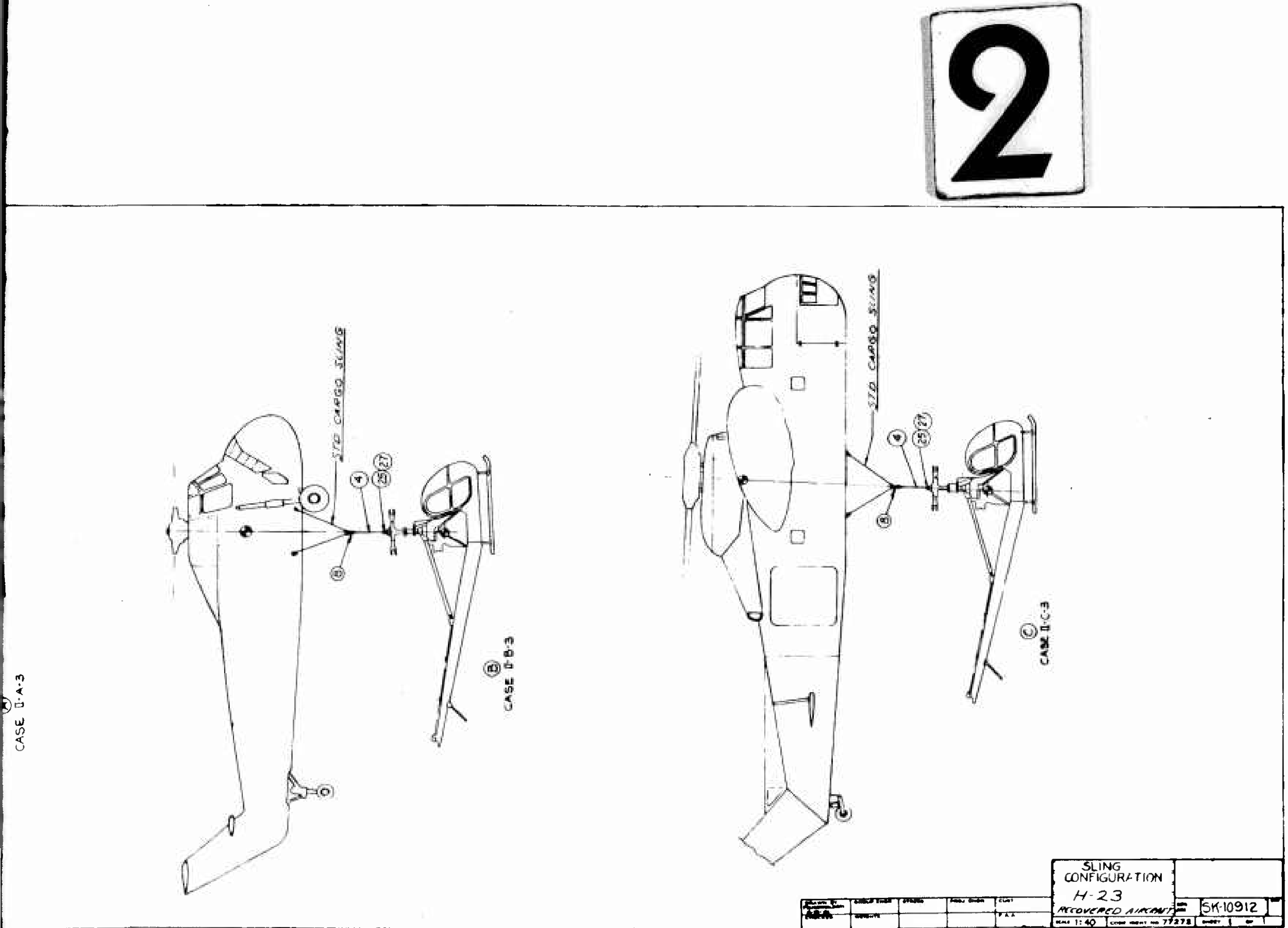
ITEM	NAME	PART NO.	WT. EACH	[illegible]	QUANTITY REQUIRED		
1	STD CARGO SLING●			1	1	1	1
2	PROTECTIVE MAT			1	-	-	-
3	YAW RESTR. CONN.			1	-	-	-
4	WIRE ROPE ASSEM.	SK10910-4		1	1	1	1
5							
6							
7							
8	HOOK ADAPTER	SK10910-8		1	1	1	1
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							
25	NUT	HILLER - 92072		1	1	1	1
26							
27	SHACKLE	AN116-8		1	1	1	1
28							
29							
30							
31							
32							
33							
34							

● AIRCRAFT EQUIPMENT - NOT PART OF KIT



(A) CASE II-A-3

1

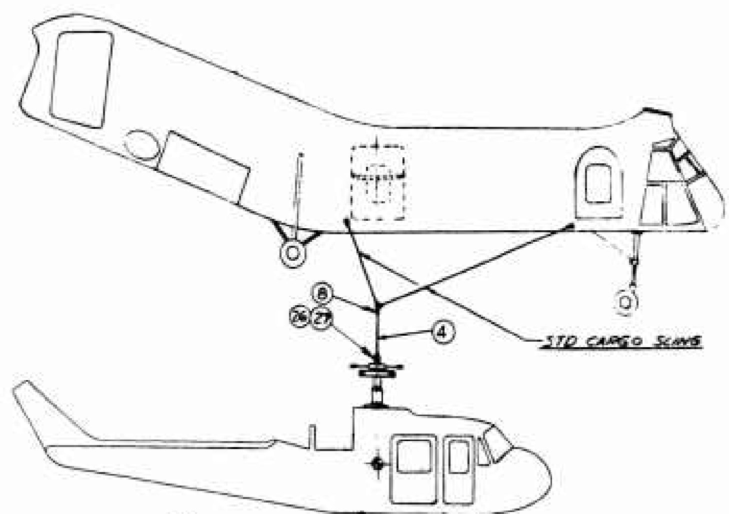

2
STD CARGO SLING
STD CARGO SLING
CASE II-A-3
CASE II-B-3
CASE II-C-3
SLING CONFIGURATION
H-23
RECOVERED AIRCRAFT
SK-10912
1:40

RECOVERED AIRCRAFT WEIGHT STRIPPING LIST HU-1A					RECOVERY AIRCRAFT		
WEIGHT EMPTY-3,916 LB.		C.G. LOCATION-142		557,576			
ITEM	GROUP	WEIGHT	ARM	MOMENT	H-21	H-34	H-37
1	ROTOR BLADES - MAIN (OR FWD)	342	132	45,178	X	X	X
2	ROTOR BLADES - TAIL (OR AFT)	45	451	20,275	X	X	X
3	ENGINE	5243	183	95,685	X	X	
4	ENGINE OIL COOLER	5.8	151.6	879			
5	OIL TANK	9.1	157.7	1,435			
6	FUEL TANK	64	136	8,704			
7	TRANSMISSION OIL COOLER	8.3	168.3	1,397			
8	TRANSMISSION - FWD	353	136	47,972			
9	TRANSMISSION - AFT	18.7	457.4	8550			
10	TRANSMISSION - CENTER	23.4	402	9,407			
11	CLUTCH MOTOR & PUMP						
12	MAIN DRIVE SHAFT	17.5	151.4	-2,650			
13	ROTOR BRAKE						
14	TRAPPED FUEL & OIL						
15	TAIL ROTOR DRIVE SHAFT	4.2	427.7	1,796			
16	TAIL ROTOR PYLON	36.7	429.7	15,770			
17	TAIL CONE OR BOOM	134.5	292.1	39,287			
18	COCKPIT						
19	CABIN						
20	ELECTRONICS						
21	HEATER	31.3	158.1	4,949			
22	WING						
23	STABILIZER						
24	RUDDER						
25	LANDING GEAR	76.1	110.2	8,387			
26	ENGINE COMPARTMENT DOORS						
27	MISCELLANEOUS						
28							
29							
30	KIT STABILIZER						

	H-21	H-34	H-37
RECOVERY WEIGHT	2,950	2,950	3,574
C.G.	131	131	138
NO. # TRIPS (MAX)	2	2	1

KIT REQUIREMENTS							
ITEM	NAME	PART NO.	WT. EACH	[illegible]	QUANTITY REQUIRED H-21	H-34	H-37
1	STD CARGO SLING*			1	/	/	/
2	PROTECTIVE MAT			1	-	-	-
3	YAW RESTR. CONN.			1	-	-	-
4	WIRE ROPE ASSEM	SK10910-4		1	1	1	1
5							
6							
7							
8	HOOK ADAPTER	SK10910-8		1	1	1	1
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							
25							
26	SHACKLE	AN116-6		1	1	1	1
27	SHACKLE	AN116-8		1	1	1	1
28							
29							
30							
31							
32							
33							
34							

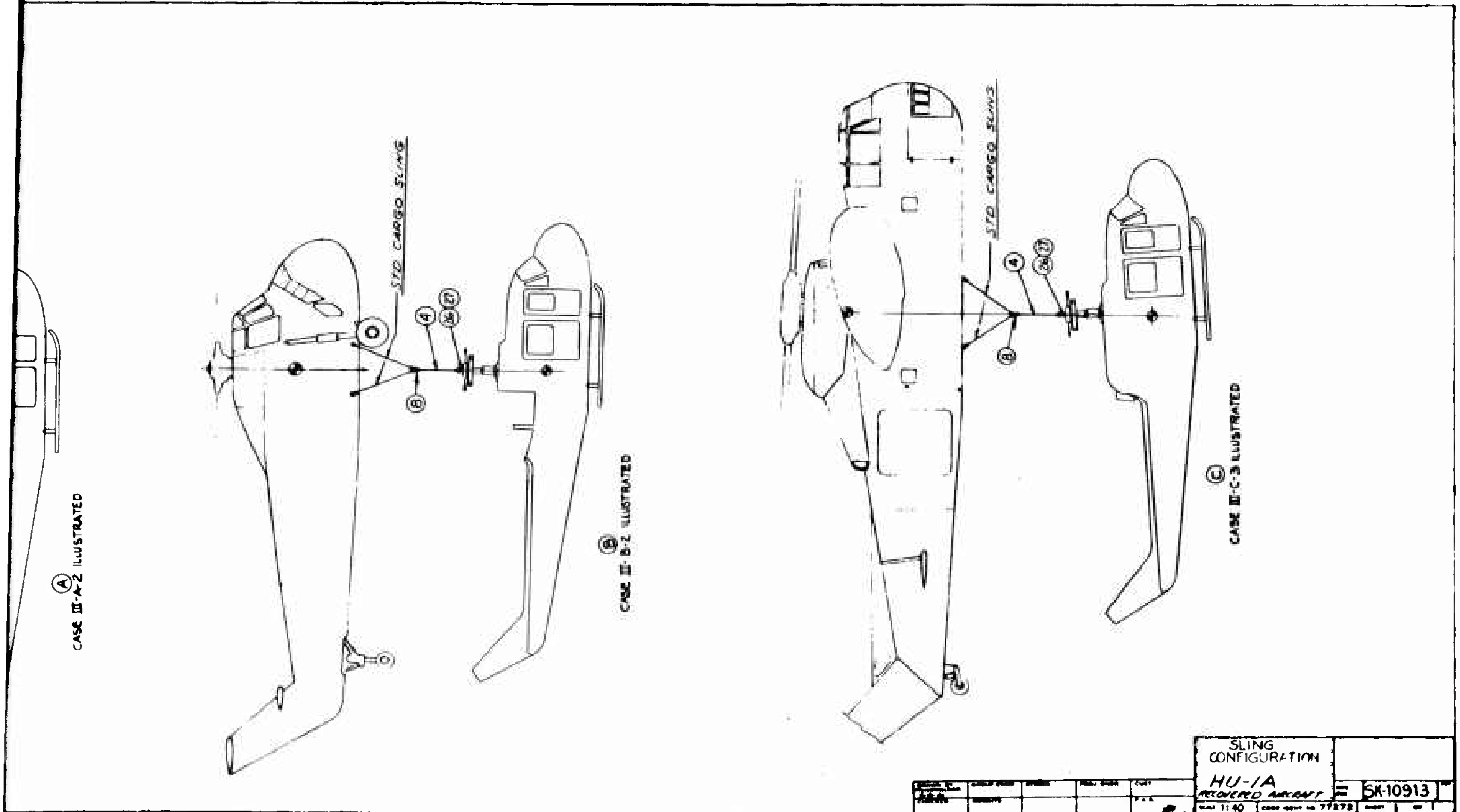
*AIRCRAFT EQUIPMENT-NOT PART OF KIT



(A) CASE III-A-2 ILLUSTRATED

1

2


STD CARGO SLING
CASE III-A-2 ILLUSTRATED
CASE III-B-2 ILLUSTRATED
STD CARGO SLING
CASE III-C-3 ILLUSTRATED
SLING CONFIGURATION
HU-1A
RECOVERED AIRCRAFT
SK-10913
1:40

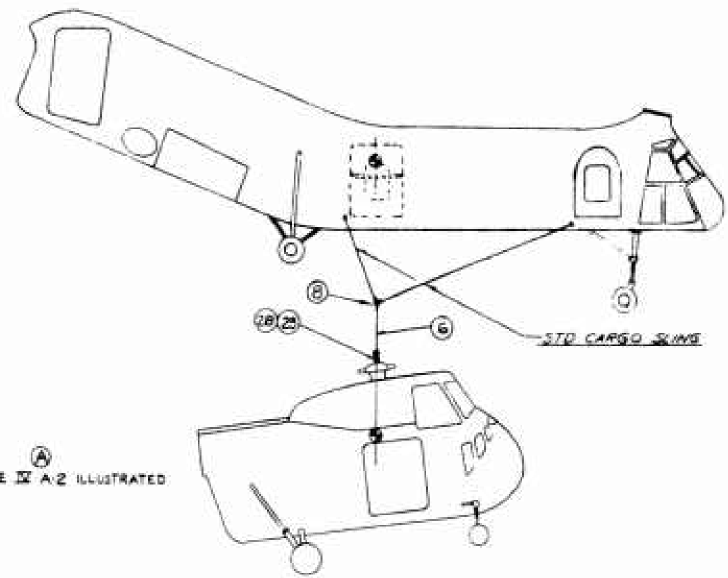
ITEM	RECOVERED AIRCRAFT WEIGHT STRIPPING LIST H-19 WEIGHT EMPTY - 5,642 LB. GROUP	C.G. LOCATION - 132 WEIGHT	ARM	744,744 MOMENT	RECOVERY AIRCRAFT H-21	H-34	H-37
1	ROTOR BLADES - MAIN (OR FWD)	423	131	55,413	X	X	X
2	ROTOR BLADES - TAIL (OR AFT)	20	506	10,120	X	X	X
3	ENGINE	1,419	48	68,112	X	X	
4	ENGINE OIL COOLER	25	65	1,625			
5	OIL TANK	15	75	1,125			
6	FUEL TANK	38	135	5,130			
7	TRANSMISSION OIL COOLER	31	163	5,053			
8	TRANSMISSION - FWD						
9	TRANSMISSION - AFT	963	131	126,153			
10	TRANSMISSION - CENTER						
11	CLUTCH MOTOR & PUMP	31	70	2,170	X	X	
12	MAIN DRIVE SHAFT	33	100	3,300	X	X	
13	ROTOR BRAKE						
14	TRAPPED FUEL & OIL	37	90	3,330	X	X	
15	TAIL ROTOR DRIVE SHAFT	55	320	17,600	X	X	
16	TAIL ROTOR PYLON	96	500	48,000	X	X	
17	TAIL CONE OR BOOM	152	370	56,240	X	X	
18	COCKPIT	190	95	18,050	X	X	
19	CABIN	89	150	13,350			
20	ELECTRONICS	234	230	53,820	X	X	
21	HEATER	77	235	18,095			
22	WING						
23	STABILIZER						
24	RUDDER						
25	LANDING GEAR [illegible]	[illegible]	[illegible]	[illegible]			
26	ENGINE COMPARTMENT DOORS	48	30	1,440	X	X	
27	MISCELLANEOUS						
28							
29							
30	KIT STABILIZER						

	H-21	H-34	H-37
RECOVERY WEIGHT	2,902	2,902	5,189
C.G.	140	140	130
NO. of TRIPS (MAX)	2	2	1

KIT REQUIREMENTS

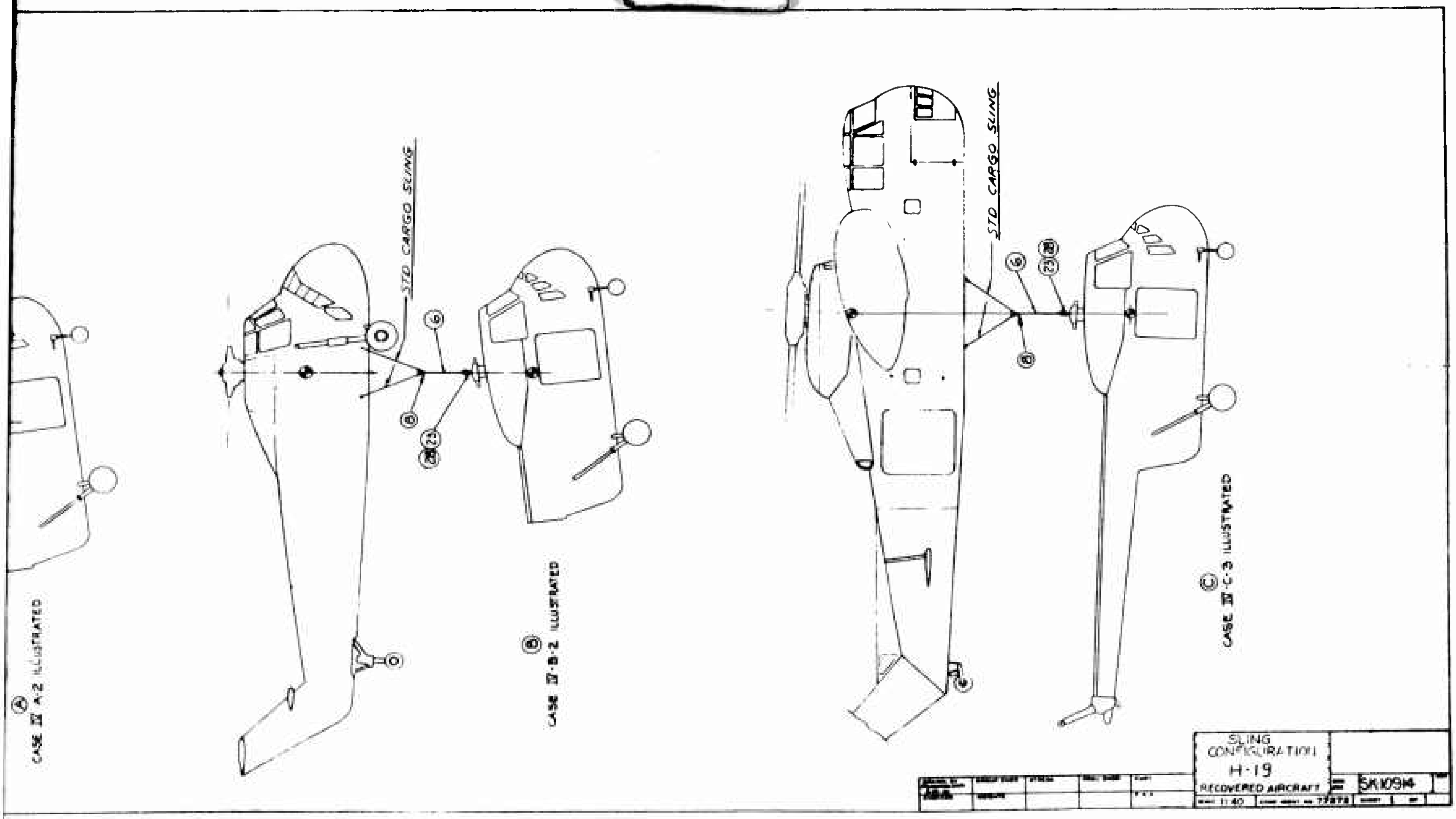
ITEM	NAME	PART NO.	[illegible]	[illegible]	QUANTITY REQUIRED H-21	H-34	H-37
1	STD CARGO SLING*			1	1	1	1
2	PROTECTIVE MAT			1	—	—	—
3	YAW RESTR. CONN.			1	—	—	—
4							
5							
6	WIRE ROPE ASSEM.	SN10910-6		1	1	1	1
7							
8	HOOK ADAPTER	SN10910-8		1	1	1	1
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23	EYEBOLT- [illegible]	512-10-1005		1	1	1	1
24							
25							
26							
27							
28	SHACKLE	AN116-12		1	1	1	1
29							
30							
31							
32							
33							
34							

*AIRCRAFT EQUIPMENT - NOT PART OF KIT



(A)
CASE IV A-2 ILLUSTRATED

2

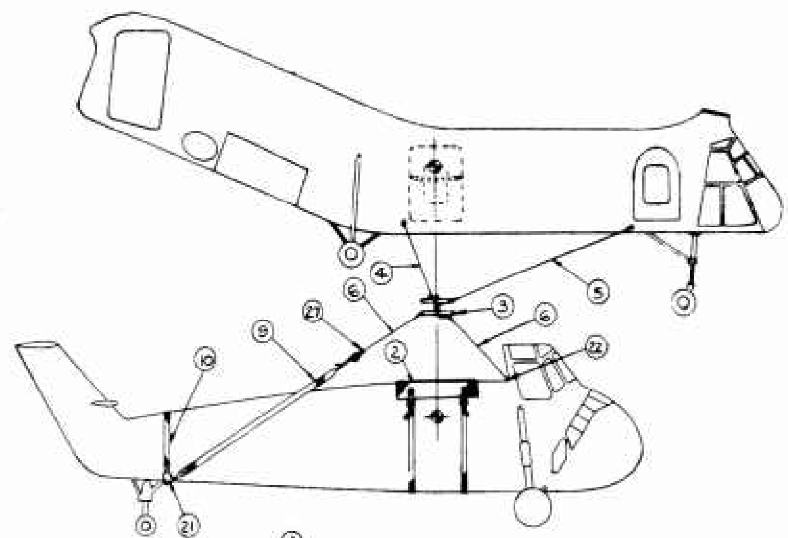

STD CARGO SLING
STD CARGO SLING
Ⓐ CASE IV A-2 ILLUSTRATED
Ⓑ CASE IV-B-2 ILLUSTRATED
Ⓒ CASE IV-C-3 ILLUSTRATED
SLING CONFIGURATION
H-19
RECOVERED AIRCRAFT
SK10914
1:40

RECOVERED AIRCRAFT WEIGHT STRIPPING LIST H-34					RECOVERY AIRCRAFT		
WEIGHT EMPTY-7,500 LB.		C.G. LOCATION-139		1,045,550			
ITEM	GROUP	WEIGHT	ARM.	MOMENT	H-21	H-34	H-37
1	ROTOR BLADES - MAIN (OR FWD)	640	137	87,680	X	X	X
2	ROTOR BLADES - TAIL (OR AFT)	20	535	10,700	X	X	X
3	ENGINE	1,887	35	66,045	X	X	
4	ENGINE OIL COOLER	45	48	2,160	X	X	
5	OIL TANK	14	66	924	X	X	
6	FUEL TANK	170	175	29,750			
7	TRANSMISSION OIL COOLER	74	175	12,950	X	X	
8	TRANSMISSION - FWD						
9	TRANSMISSION - AFT	1,545	137	211,665	X	X	
10	TRANSMISSION - CENTER						
11	CLUTCH MOTOR & PUMP	8	58	464	X	X	
12	MAIN DRIVE SHAFT	41	80	3,280	X	X	
13	ROTOR BRAKE	13	155	2,015			
14	TRAPPED FUEL & OIL	47	80	3,760			
15	TAIL ROTOR DRIVE SHAFT (PARTIAL)	63	260	16,380	X	X	
16	TAIL ROTOR PYLON AIRFRAME/DRIVE SYSTEM	126/132	500	63000/66,000	X	X	
17	TAIL CONE OR BOOM AIRFRAME/DRIVE SYSTEM	165/20	370	61,050/7400	X	X	
18	COCKPIT	101	100	10,100			
19	CABIN	93	165	15,345			
20	ELECTRONICS	133	260	34,580			
21	HEATER	29	185	5,365			
22	WING	N/A					
23	STABILIZER	N/A					
24	RUDDER	N/A					
25	LANDING GEAR	401	150	60,150			
26	ENGINE COMPARTMENT DOORS	42	30	1,260			
27	MISCELLANEOUS						
28							
29							
30	KIT STABILIZER	+100	400	40,000		⊗	
					CASE V-A-2	CASE V-B-4	CASE V-C-3

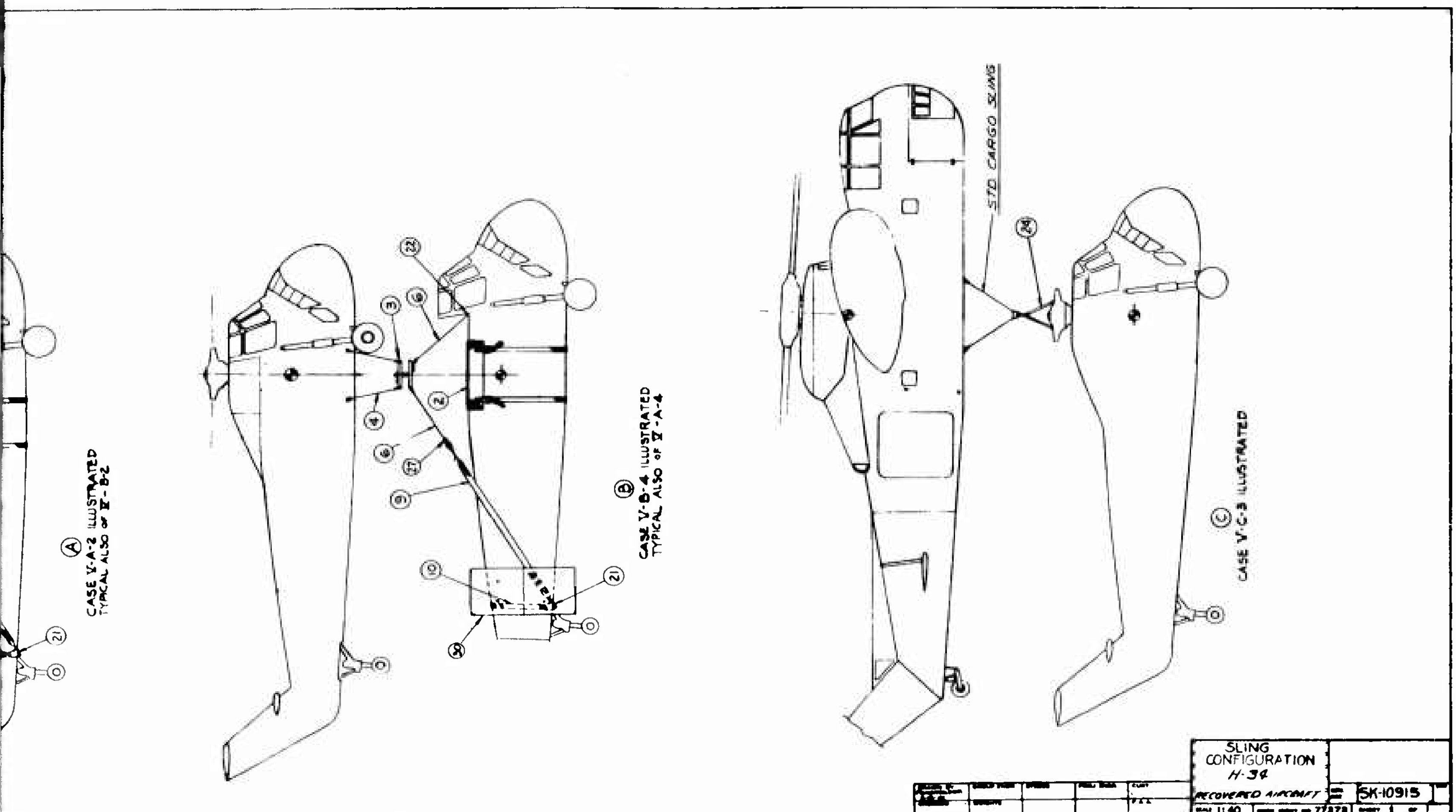
	H-21	H-34	H-37
RECOVERY WEIGHT	2,998	2807	6,840
C.G.	186	198	138.5
NO. of TRIPS (MAX)	3	3	2

KIT REQUIREMENTS (FROM SK-10910 REC. KIT)							
ITEM	NAME	PART NO.	WT. EACH	TOTAL REQ'D	QUANTITY REQUIRED H-21	H-34	H-37
1	STD CARGO SLING●			1	–	–	1
2	PROTECTIVE MAT	SK-10910-2		1	1	1	–
3	YAW RESTR. CONN.	SK-10910-3		1	1	1	1
4	WIRE ROPE ASSEM.	SK-10910-4		4	2	4	–
5	WIRE ROPE ASSEM.	SK-10910-5		2	2	–	–
6	WIRE ROPE ASSEM.	SK-10910-6		4	4	4	–
7							
8							
9	WEB STRAP ASSEM.	SK-10910-9		2	2	2	–
10	WEB STRAP ASSEM.	SK-10910-10		1	1	1	–
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21	JACK POINT FITTING	SK-10910-21			1	1	–
22	STUD & RING	SK-10910-22		2	2	2	–
23							
24							
25							
26							
27	SHACKLE	AN-116-8		1	1	1	–
28							
29							
30	STABILIZER KIT	SK-10910-30				①	
31							
32							
33							
34							
					CASE V-A-2	CASE V-B-4	CASE V-C-3

● AIRCRAFT EQUIPMENT - NOT PART OF KIT
⊗, ① DAMAGE REMOVAL CASE



(A)
CASE V-A-2 ILLUSTRATED
TYPICAL ALSO OF V-B-2



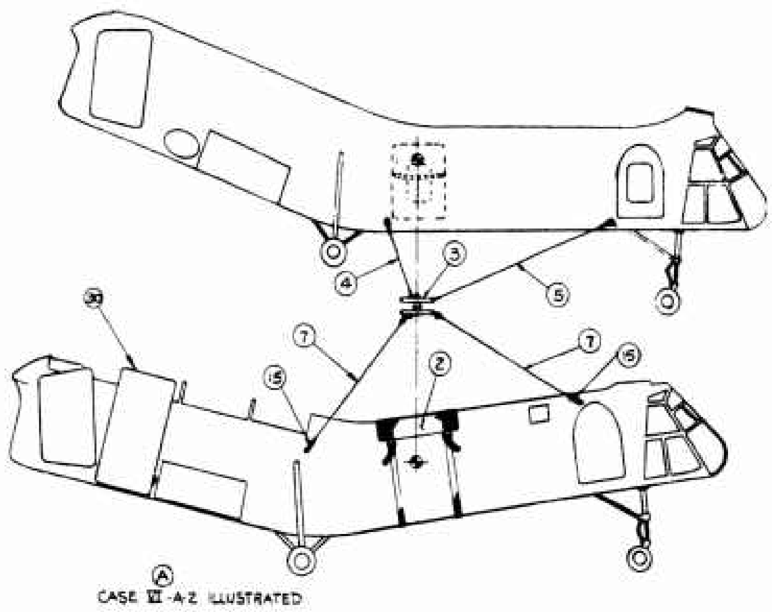
A
CASE V-A-2 ILLUSTRATED
TYPICAL ALSO of IV-B-2
B
CASE V-B-4 ILLUSTRATED
TYPICAL ALSO of IV-A-4
STD CARGO SLING
C
CASE V-C-3 ILLUSTRATED
SLING CONFIGURATION
H-34
RECOVERED AIRCRAFT
SK-10915

ITEM	RECOVERED AIRCRAFT WEIGHT STRIPPING LIST -H-21 WEIGHT EMPTY - 9345 LB. C.G. LOCATION - 353 GROUP	WEIGHT	ARM	MOMENT 3,289,785	RECOVERY AIRCRAFT H-21 (CASE VI-A 2)	H-34 (CASE VI-B2)	H-37 (CASE VI-C-4)
1	ROTOR BLADES - MAIN (OR FWD)	677	354	239,658	X	X	X
2	ROTOR BLADES - TAIL (OR AFT)						
3	ENGINE	1780	490	872,200	X	X	
4	ENGINE OIL COOLER	41.8	500	20,900	X	X	
5	OIL TANK	97.3	540	52,528	X	X	
6	FUEL TANK	156	390	61,403	X	X	
7	TRANSMISSION OIL COOLER	N/A					
8	TRANSMISSION - FWD						
9	TRANSMISSION - AFT	1758	360	633,253	X	X	X
10	TRANSMISSION - CENTER						
11	CLUTCH MOTOR & PUMP	N/A					
12	MAIN DRIVE SHAFT	107.2	354	37,949	X	X	X
13	ROTOR BRAKE	N/A					
14	TRAPPED FUEL & OIL (ALL EXCEPT FUEL IN MAIN TANKS)	261	499	130,171	X	X	
15	TAIL ROTOR DRIVE SHAFT	N/A					
16	TAIL ROTOR PYLON	N/A					
17	TAIL CONE OR BOOM	N/A					
18	COCKPIT	277	111	30,847	X	X	
19	CABIN	632	260	164,331	X	X	
20	ELECTRONICS	352.4	262	92,229	X	X	
21	HEATER	117	170	19,864	X	X	
22	WING	N/A					
23	STABILIZER	161.7	606	98,057			ⓧ
24	RUDDER	N/A					
25	LANDING GEAR	478	301	143,756			
26	ENGINE COMPARTMENT DOORS	58.3	487	28,380	X	X	
27	MISCELLANEOUS	30	230	6,900	X	X	
28							
29							
30	KIT STABILIZER	(+) 100	550	(+) 55,000	X	X	X

	H-21	H-34	H-37
RECOVERY WEIGHT	3000	3000	6803
C.G.	308	308	336
NO. OF TRIPS (MAX)	4	4	2

ITEM	KIT REQUIREMENTS (FROM SK10910 REC. KIT) NAME	PART NO.	WT. EACH	TOTAL REQ'D	QUANTITY REQUIRED H-21 (CASE VI-A-2)	H-34 (CASE VI-B-2)	H-37 (CASE VI-C-4)
1	STD CARGO SLING*			1	–	–	–
2	PROTECTIVE MAT			1	1	1	1
3	YAW RESTR. CONN.			1	1	1	1
4	WIRE ROPE ASSEM.	SK-10910-4		4	2	4	4
5	WIRE ROPE ASSEM.	SK-10910-5		2	2	–	–
6							
7	WIRE ROPE ASSEM.	SK-10910-7		4	4	4	4
8							
9							
10							
11							
12							
13							
14							
15	ADAPTER	SK10910-15		4	4	4	4
16							
17							
18							
19							
20							
21							
22							
23							
24							
25							
26							
27							
28							
29							
30	STABILIZER KIT	SK10910-30		1	1	1	1
31							
32							
33							
34							

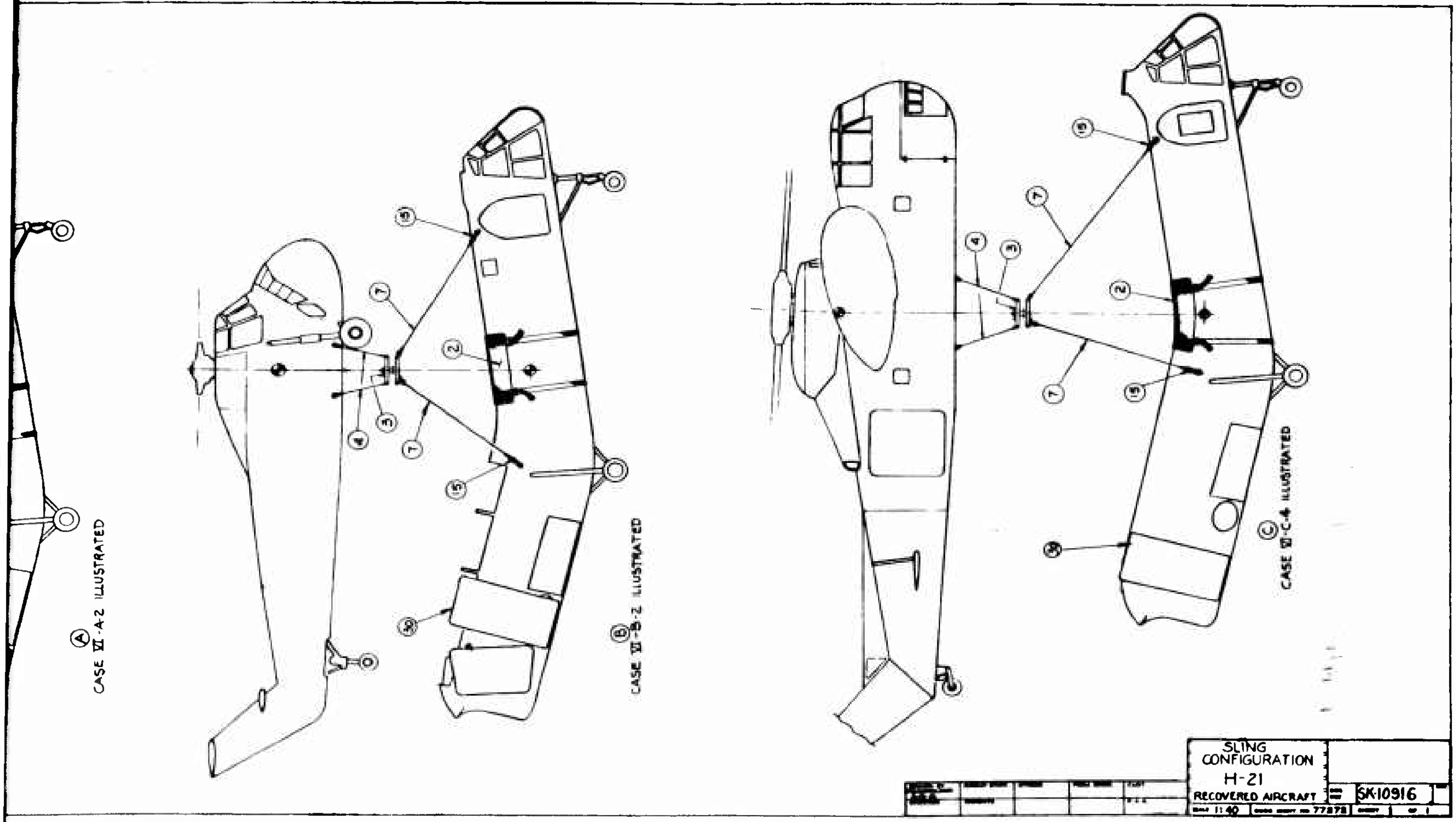
*AIRCRAFT EQUIPMENT - NOT PART OF KIT
ⓧ INDICATES DAMAGE REMOVAL



Ⓐ CASE VI-A-2 ILLUSTRATED

1

2


CASE VI-A-2 ILLUSTRATED
CASE VI-B-2 ILLUSTRATED
CASE VI-C-4 ILLUSTRATED
SLING CONFIGURATION
H-21
RECOVERED AIRCRAFT
SK-10916

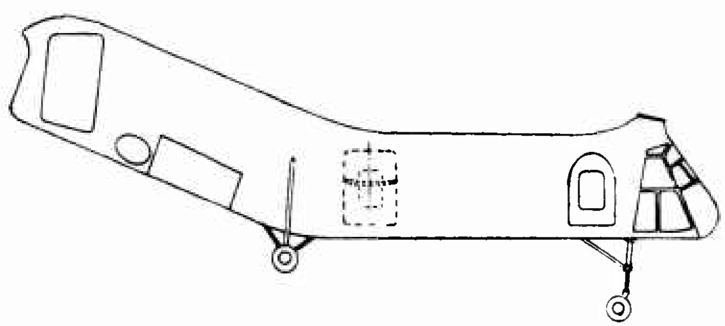
RECOVERED AIRCRAFT WEIGHT STRIPPING LIST H-37					RECOVERY AIRCRAFT		
WEIGHT EMPTY-20,116 LB		C.G. LOCATION-242		4,877,280			
ITEM	GROUP	WEIGHT	ARM	MOMENT	H-21	H-34	H-37
1	ROTOR BLADES - MAIN (OR FWD)	1,605	236	378,780			X
2	ROTOR BLADES - TAIL (OR AFT)	116	730	84,680			X
3	ENGINE	6,134	184	1,128,656			X
4	ENGINE OIL COOLER	80	200	16,000			
5	OIL TANK	23	220	5,060			
6	FUEL TANK	162	230	37,260			
7	TRANSMISSION OIL COOLER	60	265	15,900			X
8	TRANSMISSION - FWD						
9	TRANSMISSION - AFT	3,673	240	881,520			X
10	TRANSMISSION - CENTER						
11	CLUTCH MOTOR & PUMP	50	210	10,500			X
12	MAIN DRIVE SHAFT	104	190	19,760			X
13	ROTOR BRAKE	20	260	5,200			X
14	TRAPPED FUEL & OIL	181	217	39,277			X
15	TAIL ROTOR DRIVE SHAFT	214	500	107,000			X
16	TAIL ROTOR PYLON - [illegible]	[illegible]/130	680	[illegible]			[illegible]
17	TAIL CONE OR BOOM						
18	COCKPIT	127	80	10,160			
19	CABIN	842	250	210,500			
20	ELECTRONICS	302	125	37,750			X
21	HEATER	253	330	83,490			X
22	WING						
23	STABILIZER						
24	RUDDER						
25	LANDING GEAR [illegible]	[illegible]	[illegible]	[illegible]			
26	ENGINE COMPARTMENT DOORS	104	160	16,640			
27	MISCELLANEOUS						
28							
29							
30	KIT STABILIZER	(-)100	575	(-)57,500			X

	H-21	H-34	H-37
RECOVERY WEIGHT	–	–	1038
C.G.	–	–	243
NO. of TRIPS	–	–	3

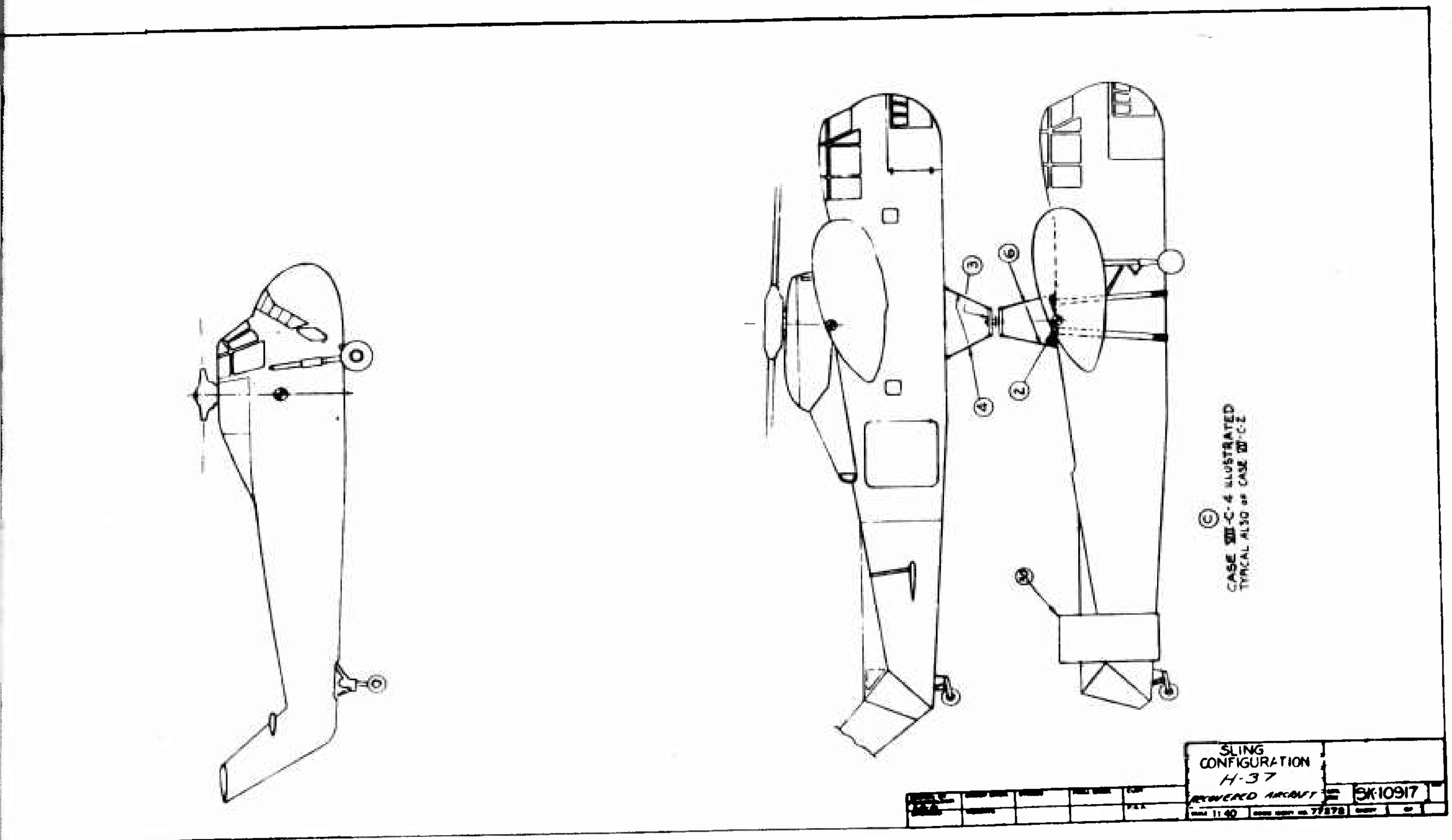
CASE VII-C-4

KIT REQUIREMENTS (FROM SH-1090 REC. KIT)							
ITEM	NAME	PART NO.	[illegible]	[illegible]	QUANTITY REQUIRED		
1	STD CARGO SLING*			1	–	–	–
2	PROTECTIVE MAT			1	–	–	1
3	YAW RESTR. CONN.			1	–	–	1
4	WIRE ROPE ASSEM.	SH1090-4		4			4
5							
6	WIRE ROPE ASSEM.	SH1090-6		4			4
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							
25							
26							
27							
28							
29							
30	STABILIZER FIN	SH1090-30		1			1
31							
32							
33							
34							

* AIRCRAFT EQUIPMENT - NOT PART OF KIT
Ⓓ INDICATES DAMAGE REMOVAL



2

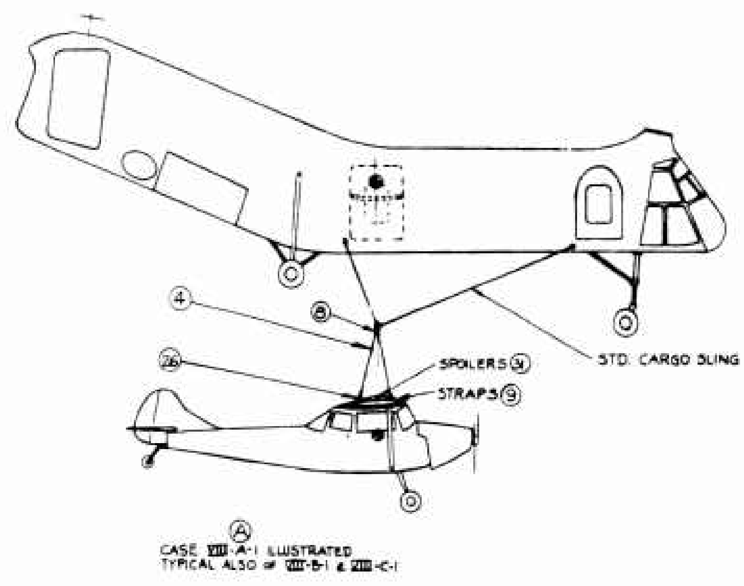


ITEM	GROUP	WEIGHT	ARM	MOMENT	RECOVERY AIRCRAFT #21	H-34	#37
	RECOVERED AIRCRAFT WEIGHT STRIPPING LIST · L-19 WEIGHT EMPTY - 1700 LB C.G. LOCATION - 134 = 227,800						
1	ROTOR BLADES - MAIN (OR FWD)						
2	ROTOR BLADES - TAIL (OR AFT)						
3	ENGINE	533	85	45,305			⊗
4	ENGINE OIL COOLER						
5	OIL TANK						
6	FUEL TANK						
7	TRANSMISSION OIL COOLER						
8	TRANSMISSION - FWD						
9	TRANSMISSION - AFT						
10	TRANSMISSION - CENTER						
11	CLUTCH MOTOR & PUMP						
12	MAIN DRIVE SHAFT						
13	ROTOR BRAKE						
14	TRAPPED FUEL & OIL	4	97.5	390			
15	TAIL ROTOR DRIVE SHAFT						
16	TAIL ROTOR PYLON						
17	TAIL CONE OR BOOM						
18	COCKPIT	79	135	10,665			
19	CABIN						
20	ELECTRONICS	113	154	17402			
21	HEATER						
22	WING	250	133	33250			
23	STABILIZER	39	328	12,792		⊗	
24	RUDDER	26	305	7930		⊗	
25	LANDING GEAR MAIN/TAIL	126/15	119/338	15009/5070			
26	ENGINE COMPARTMENT DOORS						
27	MISCELLANEOUS						
28							
29							
30	KIT STABILIZER	(+) 70	300	(+) 21000		⊗	
					CASE VIII-A-1	CASE VIII-B-4	CASE VIII-C-6

	H-21	H-34	H-37
RECOVERY WEIGHT	1700	1705	1166
C.G.	134	134	156
NO. OF TRIPS (MAX)	1	1	1

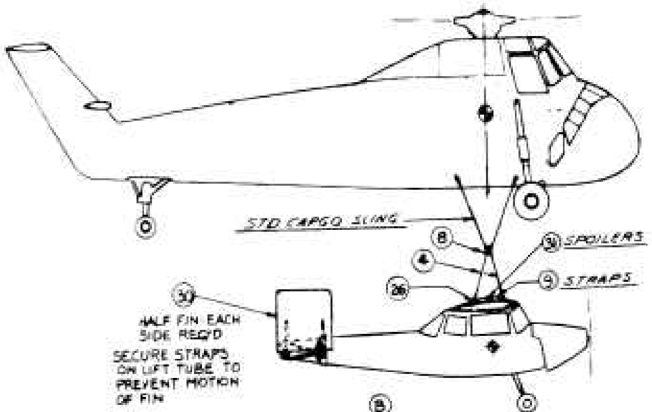
ITEM	NAME	PART NO.	WT. EACH	TOTAL REQ'D	QUANTITY REQUIRED H-21	H-34	H-37
	KIT REQUIREMENTS (FROM SK-10910 REC. KIT)						
1	STD CARGO SLING●			1	1	1	1
2	PROTECTIVE MAT			1			
3	YAW RESTR. CONN.			1	-	-	-
4	WIRE ROPE ASSEM.	SK-10910-4		4	4	4	4
5							
6							
7							
8	HOOK ADAPTER	SK-10910-8		*2	2	2	2
9	WEB STRAP ASSEM	SK-10910-9					②
10	WEB STRAP ASSEM	SK-10910-10					①
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							
25							
26	SHACKLE	AN-116-5		4	4	4	4
27	SHACKLE	AN-116-8					①
28							
29							
30	STABILIZER KIT	SK-109103				①	
31	SPOILERS	WOOD 2×4		30'	30'	30'	30'
32							
33							
34							
					CASE VIII-A-1	CASE VIII-B-4	CASE VIII-C-6

● AIRCRAFT EQUIPMENT - NOT PART OF KIT
⊗, ①, ② DAMAGE REMOVAL CASE

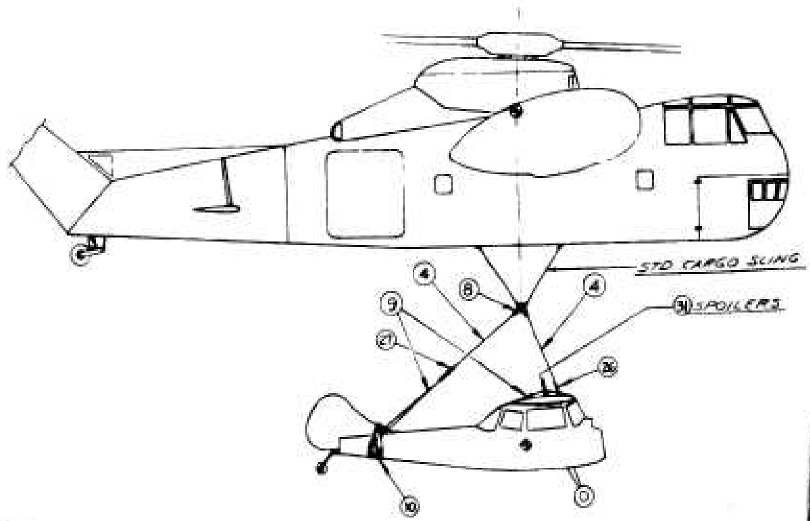


Ⓐ
CASE VIII-A-1 ILLUSTRATED
TYPICAL ALSO of VIII-B-1 & VIII-C-1

Ⓐ CASE VIII-A-1 ILLUSTRATED
TYPICAL ALSO OF VIII-B-1 & VIII-C-1



Ⓑ CASE VIII-B-4 ILLUSTRATED
TYPICAL ALSO OF VIII-A-4 & VIII-C-4



Ⓒ CASE VIII-C-6 ILLUSTRATED
TYPICAL ALSO OF VIII-A-6 & VIII-B-6

SLING CONFIGURATION
L-19
RECOVERED AIRCRAFT
SK10918

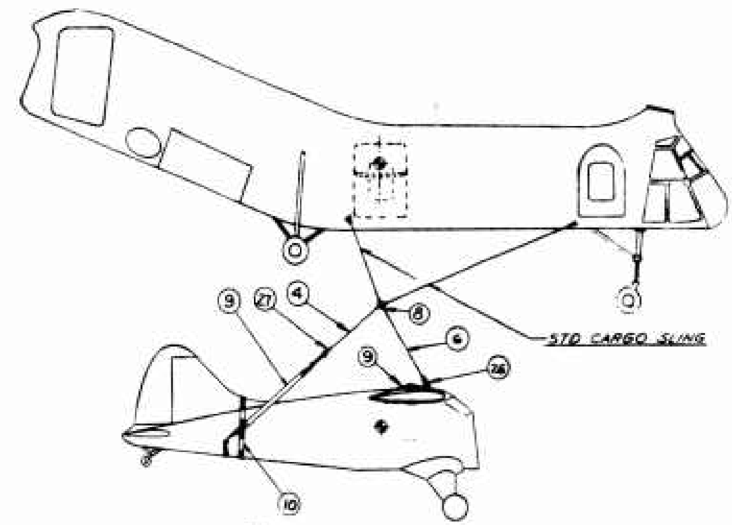
ITEM	RECOVERED AIRCRAFT WEIGHT STRIPPING LIST L-20A — WEIGHT EMPTY-3,202 LB — GROUP	WEIGHT	C.G. LOCATION-100 ARM	320,200 MOMENT	RECOVERY AIRCRAFT H-21 (CASE III-A-G)	H-34 (CASE III-B-4)	H-37 (CASE III-C-1)
1	ROTOR BLADES - MAIN (OR FWD)						
2	ROTOR BLADES - TAIL (OR AFT)						
3	ENGINE	879	38	33,211	⊗		
4	ENGINE OIL COOLER	10	65	650			
5	OIL TANK	5	63	315			
6	FUEL TANK	39	116	4,524			
7	TRANSMISSION OIL COOLER						
8	TRANSMISSION - FWD						
9	TRANSMISSION - AFT						
10	TRANSMISSION - CENTER						
11	CLUTCH MOTOR & PUMP						
12	MAIN DRIVE SHAFT						
13	ROTOR BRAKE						
14	TRAPPED FUEL & OIL	24	81	1,944			
15	TAIL ROTOR DRIVE SHAFT						
16	TAIL ROTOR PYLON						
17	TAIL CONE OR BOOM						
18	COCKPIT	91	84	7,644			
19	CABIN	112	138	15,456			
20	ELECTRONICS	142	185	26,270			
21	HEATER	N/A					
22	WING	484	110	53,240		X	
23	STABILIZER	64	344	22,016		⊗	
24	RUDDER	27	320	8,640		⊗	
25	LANDING GEAR (MAIN) (TAIL)	236 / 31	[illegible]	[illegible]			
26	ENGINE COMPARTMENT DOORS						
27	MISCELLANEOUS						
28	PROPELLER	175	125 STRIPPED	21,875			
29							
30	KIT STABILIZER	(+)100	320	(+)32000		⊗	

	H-21	H-34	H-37
RECOVERY WEIGHT	2,323	2727	3,202
C.G.	123	99	108
NO. OF TRIPS (MAX)	2	2	1

KIT REQUIREMENTS (FROM SK10910 REC KIT)

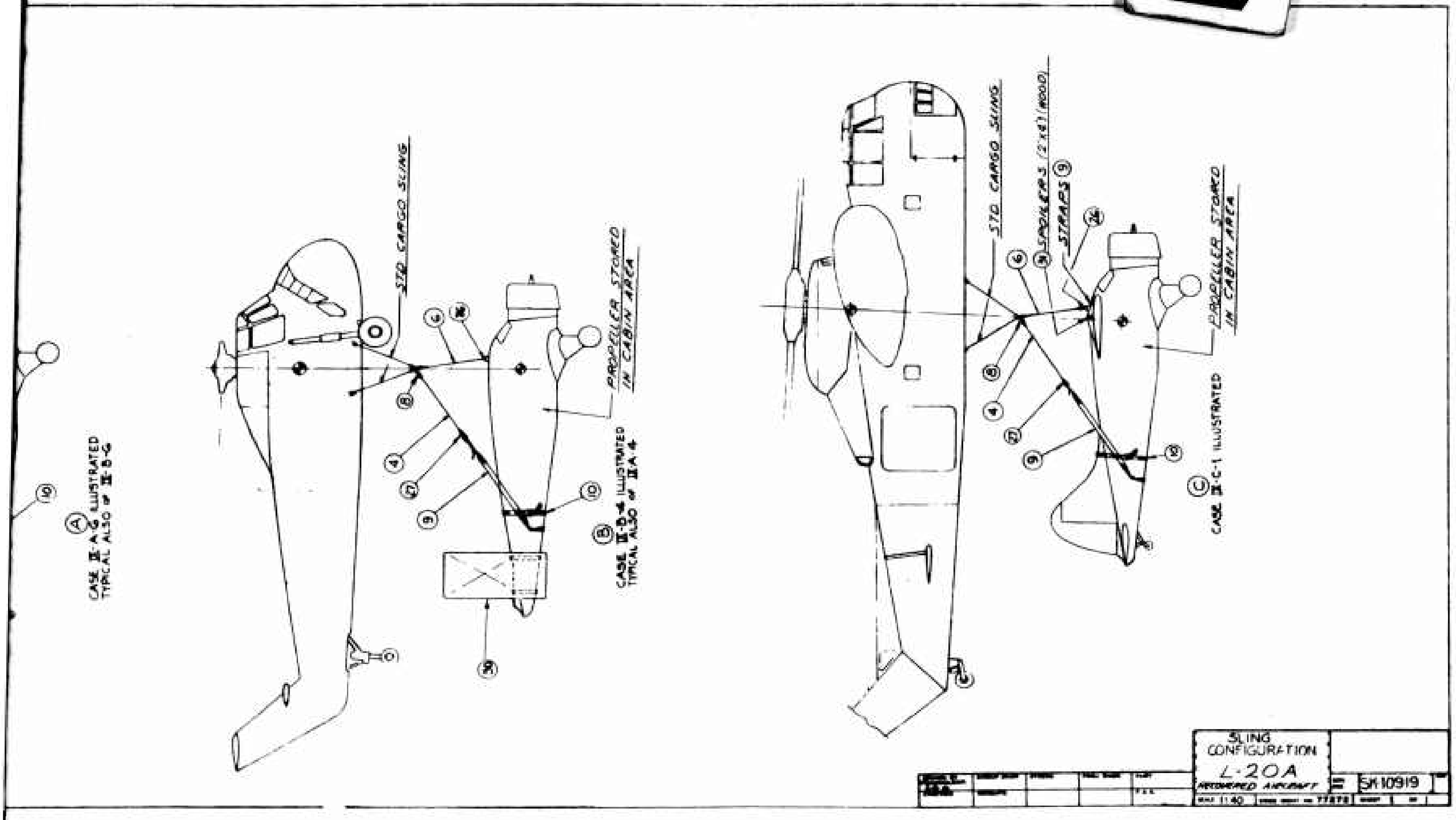
ITEM	NAME	PART NO.		UNIT PER KIT	QUANTITY REQUIRED CASE III-A-G	CASE III-B-4	CASE III-C-1
1	STD CARGO SLING●			1	1	1	1
2	PROTECTIVE MAT			1	–	–	–
3	YAW RESTR. CONN.			1	–	–	–
4	WIRE ROPE ASSEM.	SK-10910-4		2	2	2	2
5							
6	WIRE ROPE ASSEM.	SK-10910-6		2	2	2	2
7							
8	HOOK ADAPTER	SK-10910-8		2	2	2	2
9	WEB STRAP	SK-10910-9		4	2	2	4
10	WEB STRAP	SK-10910-10		1	1	1	1
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							
25							
26	SHACKLE	AN-116-5		2	2	2	2
27	SHACKLE	AN-116-8		1	1	1	1
28							
29							
30	STABILIZER KIT	SK-10910-30				1	
31	SPOILERS	WOOD 2x4		20			20
32							
33							
34							

● AIRCRAFT EQUIPMENT - NOT PART OF KIT
⊗, ① DAMAGE REMOVAL CASE



A
CASE III-A-G ILLUSTRATED
TYPICAL ALSO OF III-B-G

1


STD CARGO SLING
PROPELLER STORED IN CABIN AREA
CASE II-A-G ILLUSTRATED TYPICAL ALSO of II-B-G
CASE II-B-4 ILLUSTRATED TYPICAL ALSO of II-A-4
STD CARGO SLING
SPOILERS (2"x4") (WOOD)
STRAPS
PROPELLER STORED IN CABIN AREA
CASE II-C-1 ILLUSTRATED
SLING CONFIGURATION
L-20A
SK10919

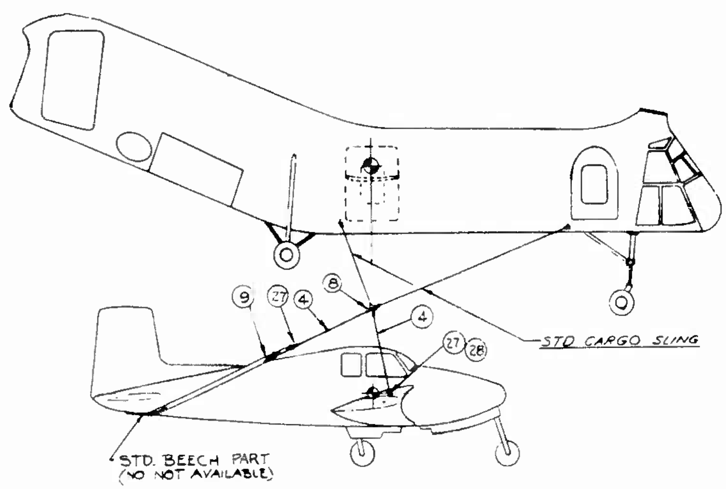
ITEM	RECOVERED AIRCRAFT WEIGHT STRIPPING LIST 4-23 WEIGHT EMPTY - 3,995 LB / GROUP	C.G. LOCATION - 114 / WEIGHT	ARM	455,430 / MOMENT	RECOVERY AIRCRAFT H-21	H-34	H-37
1	ROTOR BLADES - MAIN (OR FWD)						
2	ROTOR BLADES - TAIL (OR AFT)						
3	ENGINE	1,366	70	95,620	X	X	
4	ENGINE OIL COOLER	15	72	1,080			
5	OIL TANK						
6	FUEL TANK	35	125	4,375			
7	TRANSMISSION OIL COOLER						
8	TRANSMISSION - FWD						
9	TRANSMISSION - AFT						
10	TRANSMISSION - CENTER						
11	CLUTCH MOTOR & PUMP						
12	MAIN DRIVE SHAFT						
13	ROTOR BRAKE						
14	TRAPPED FUEL & OIL	9	110	990			
15	TAIL ROTOR DRIVE SHAFT						
16	TAIL ROTOR PYLON						
17	TAIL CONE OR BOOM						
18	COCKPIT	219	127	27,813			
19	CABIN						
20	ELECTRONICS	139	80	11,120			
21	HEATER	38	73	2,774			
22	WING	318	125	39,750			
23	STABILIZER	101	335	33,835		⊗	
24	RUDDER	46	325	14,950		⊗	
25	LANDING GEAR	324	100	32,400			
26	ENGINE COMPARTMENT DOORS						
27	MISCELLANEOUS						
28							
29							
30	KIT STABILIZER	+100	320	32,000			
					CASE X-A-2	CASE X-B-4	CASE X-C-1

	H-21	H-34	H-37
RECOVERY WEIGHT	2629	2582	3,995
C.G.	137	133	114
NO. OF TRIPS (MAX)	2	2	1

ITEM	KIT REQUIREMENTS (FROM SK-10910 REC KIT) / NAME	PART NO.	WT. EACH	TOTAL REQ'D	QUANTITY REQUIRED H-21	H-34	H-37
1	STD CARGO SLING●			1	/	/	/
2	PROTECTIVE MAT			1	–	–	–
3	YAW RESTR. CONN.			1	–	–	–
4	WIRE ROPE ASSEM.	SK-10910-4		4	4	4	4
5							
6							
7							
8	HOOK ADAPTER	SK-10910-8		2	2	2	2
9	WEB STRAP	SK-10910-9		6	2	2.	4
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							
25							
26	SHACKLE	AN-116-5		2	–	–	1
27	SHACKLE	AN-116-8		4	3	3	3
28	SHACKLE	AN-116-12		2	2	2	2
29							
30	STABILIZER KIT	SK-10910-30				①	
31	SPOILERS	WOOD 2x4		20'	–	–	20'
32							
33							
34							
					CASE X-A-2	CASE X-B-4	CASE X-C-1

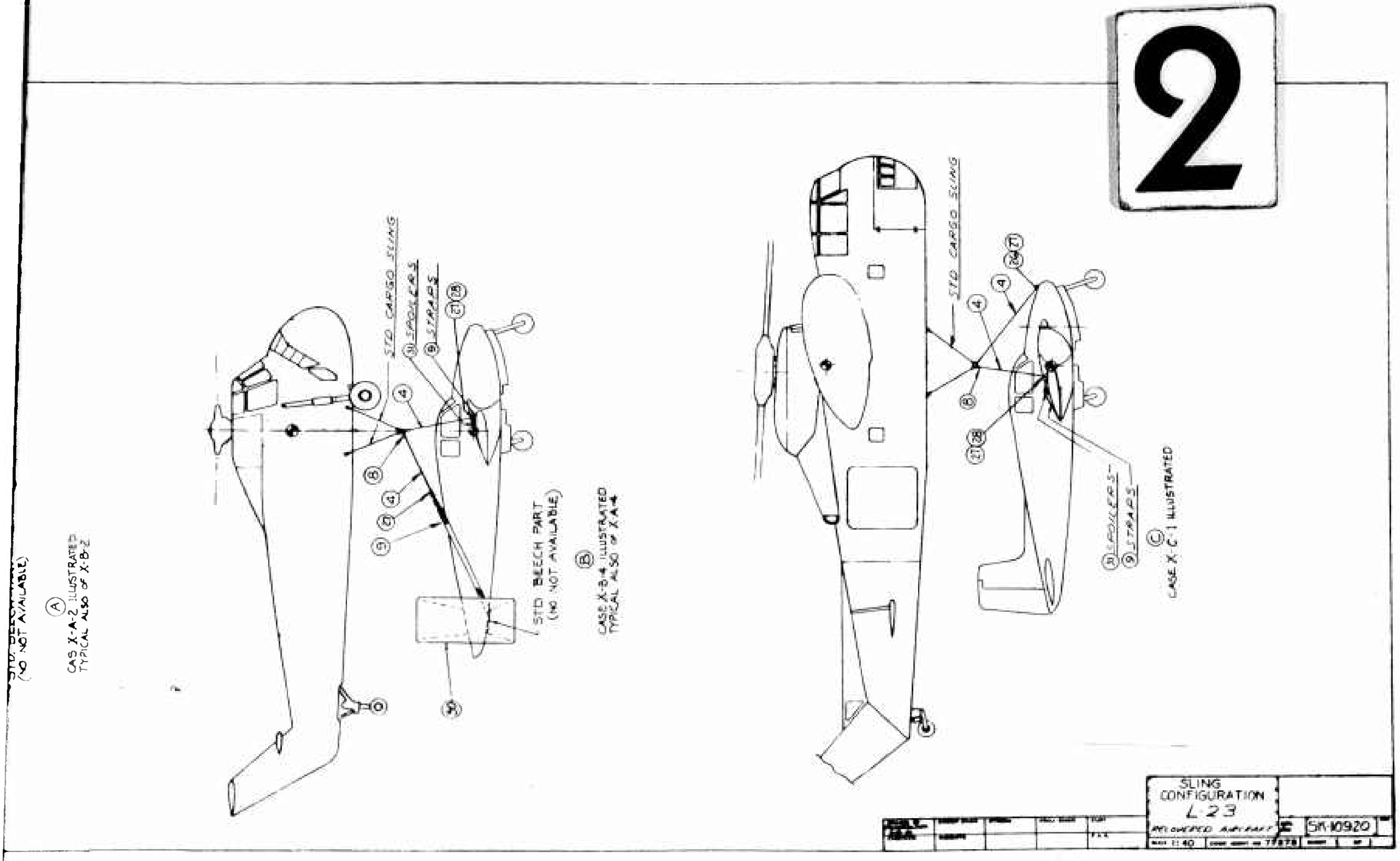
● AIRCRAFT EQUIPMENT - NOT PART OF KIT

⊗, ① DAMAGE REMOVAL CASE



A

CAS X-A-2 ILLUSTRATED
TYPICAL ALSO OF X-B-2


2
STD CARGO SLING
SPOILERS
STRAPS
STD BEECH PART (NO NOT AVAILABLE)
CASE X-B-4 ILLUSTRATED TYPICAL ALSO OF X-A-4
CAS X-A-2 ILLUSTRATED TYPICAL ALSO OF X-B-2
STD CARGO SLING
SPOILERS
STRAPS
CASE X-C-1 ILLUSTRATED
SLING CONFIGURATION
L-23
SK-10920

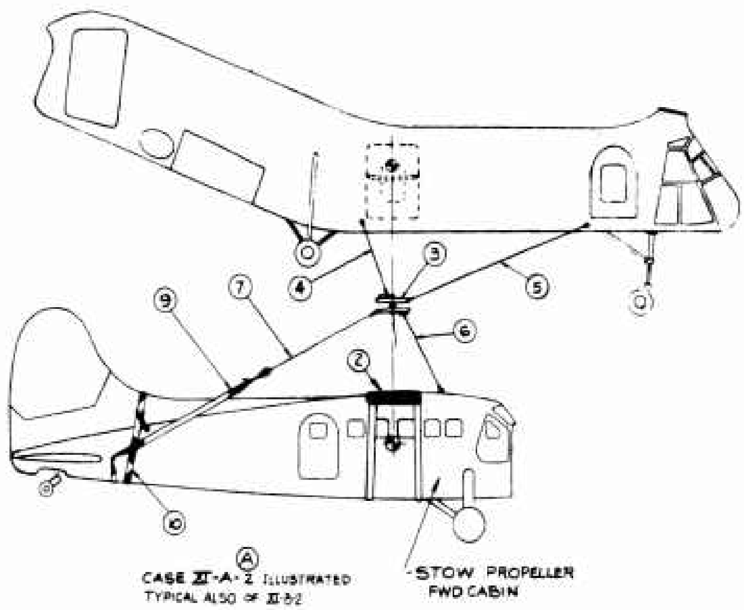
RECOVERED AIRCRAFT WEIGHT STRIPPING LIST WEIGHT LIMIT - 4848 LB		U/A LOCATION - 117		567,216	RECOVERY AIRCRAFT		
ITEM	GROUP	WEIGHT	ARM	MOMENT	H21	H34	H37
1	ROTOR BLADES - MAIN (OR FWD)						
2	ROTOR BLADES - TAIL (OR AFT)						
3	ENGINE	1204	40	48,160	X	X	
4	ENGINE OIL COOLER	18	36	648			
5	OIL TANK	18	50	900			
6	FUEL TANK	60	50	3000			
7	TRANSMISSION OIL COOLER						
8	TRANSMISSION - FWD						
9	TRANSMISSION - AFT						
10	TRANSMISSION - CENTER						
11	CLUTCH MOTOR & PUMP						
12	MAIN DRIVE SHAFT						
13	ROTOR BRAKE						
14	TRAPPED FUEL & OIL (INCL ENG OIL)	117	40	4680	X	X	
15	TAIL ROTOR DRIVE SHAFT						
16	TAIL ROTOR PYLON						
17	TAIL CONE OR BOOM						
18	COCKPIT	263					
19	CABIN	122					
20	ELECTRONICS	500					
21	HEATER	48					
22	WING	768	140	107,520	X	X	
23	STABILIZER	129	470	60,630		Ⓧ	
24	RUDDER	67	450	30,150		Ⓧ	
25	LANDING GEAR [illegible]	423	[illegible]	[illegible]			
26	ENGINE COMPARTMENT DOORS						
27	MISCELLANEOUS						
28	PROPELLER	304	100 (STOW)	30,400			
29							
30	KIT STABILIZER	(+)100	450	(+)45,000		Ⓑ	
					CASE II-A-2	CASE II-B-4	CASE II-C-1

	H-21	H-34	H-37
RECOVERY WEIGHT	2759	2859	4848
C.G.	157	146	131
NO. OF TRIPS (MAX)	2	2	1

KIT REQUIREMENTS (FROM SK10910 REC KIT)							
ITEM	NAME	PART NO.	WT. EACH	TOTAL PER KIT	QUANTITY REQUIRED H21	H34	H37
1	STD CARGO SLING*			1	—	—	—
2	PROTECTIVE MAT	SK10910-2		1	1	1	1
3	YAW RESTR. CONN.	SK10910-3		1	1	1	1
4	WIRE ROPE ASSEM.	SK10910-4		4	2	4	4
5		-5		2	2	-	-
6		-6		2	2	2	2
7	WIRE ROPE ASSEM.	-7		2	2	2	2
8							
9	WEB STRAP ASSEM.	-9		6	2	2	6
10	WEB STRAP ASSEM.	-10		1	1	1	1
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							
25							
26							
27	SHACKLE	AN-116-8		1	1	1	1
28							
29							
30	STABILIZER KIT					①	
31	SPOILERS	WOOD 2x4		40'	-	-	40'
32							
33							
34							
					CASE II-A-2	CASE II-B-4	CASE II-C-1

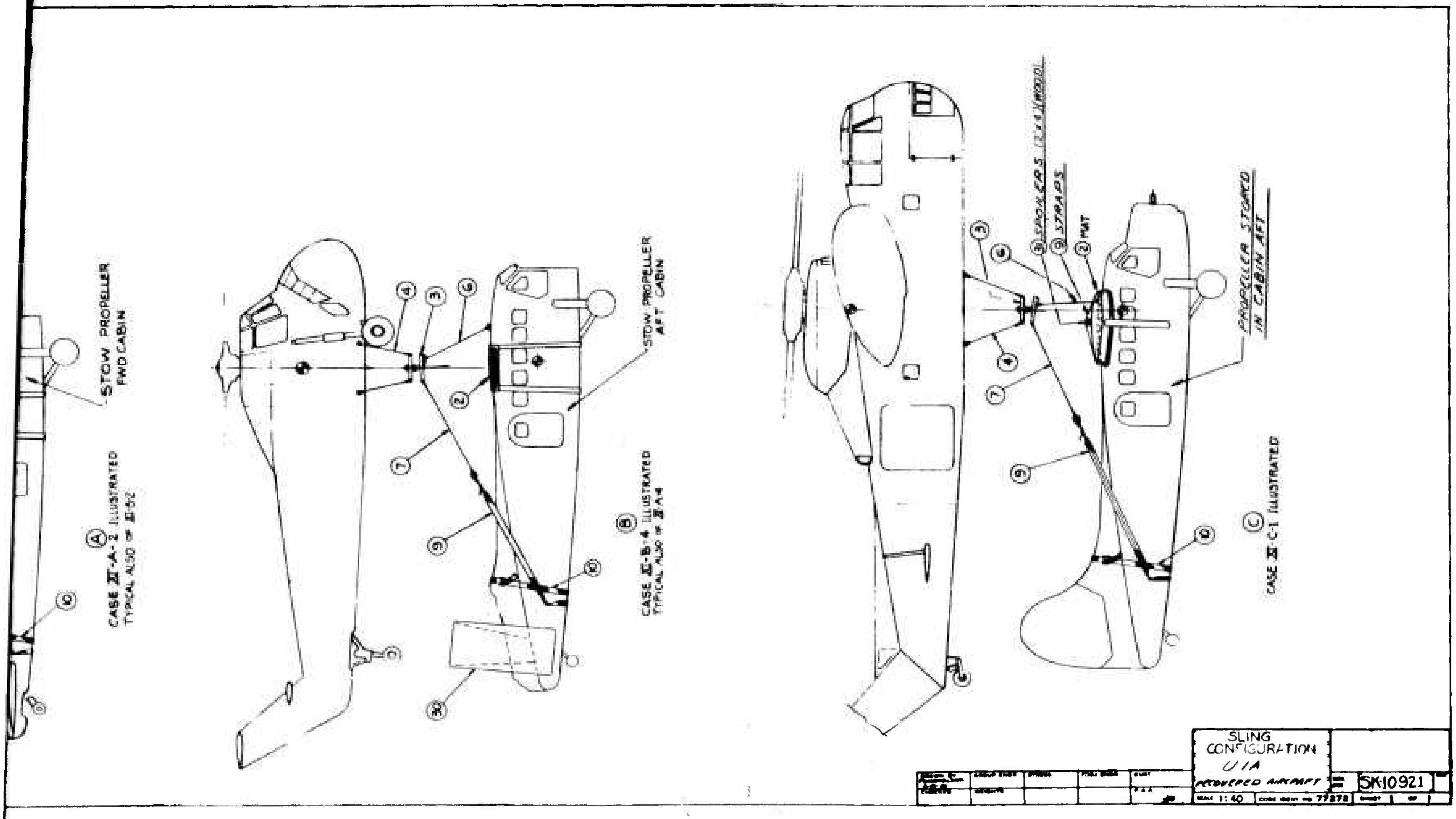
*AIRCRAFT EQUIPMENT - NOT PART OF KIT

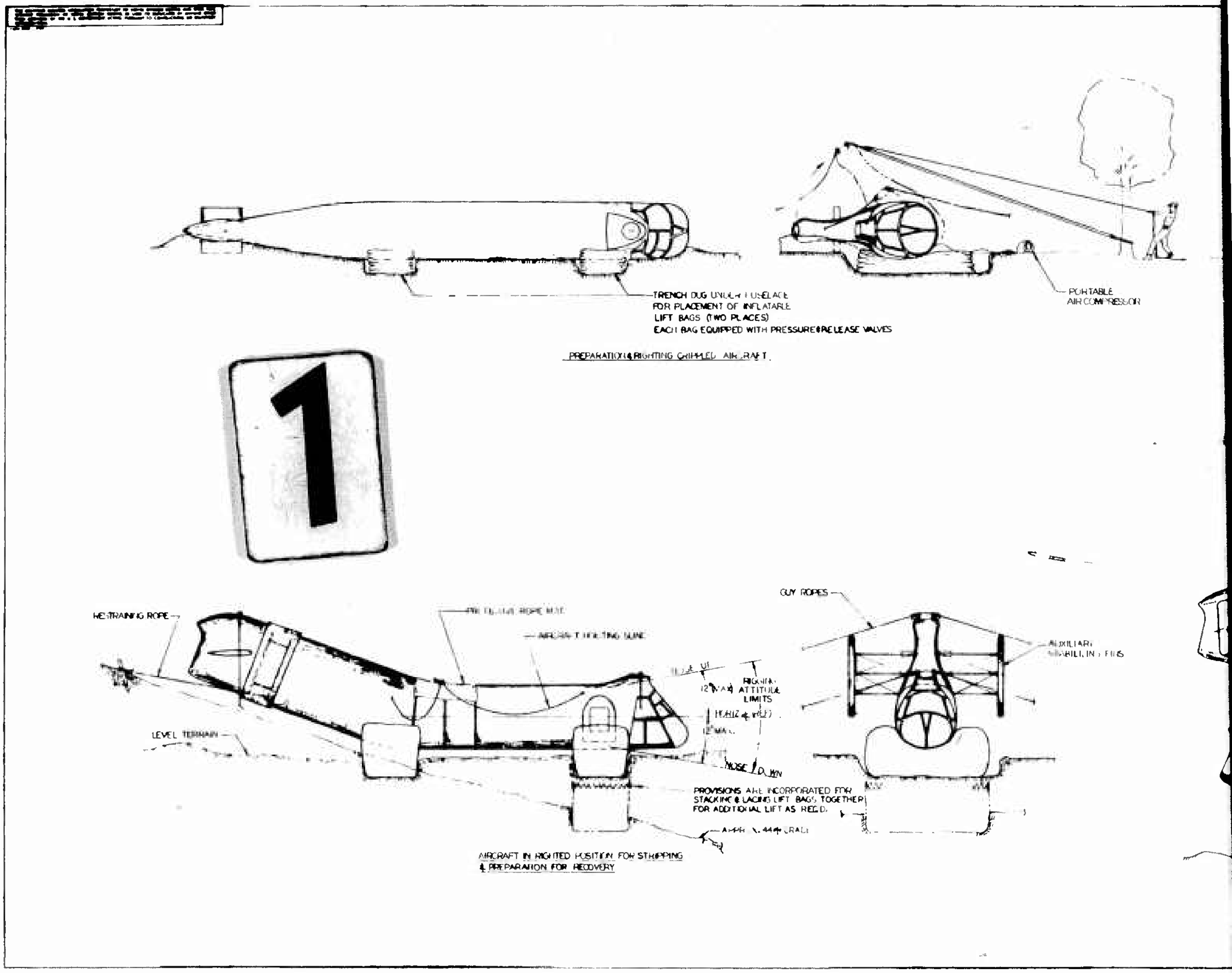
Ⓐ,① DAMAGE REMOVAL CASE.

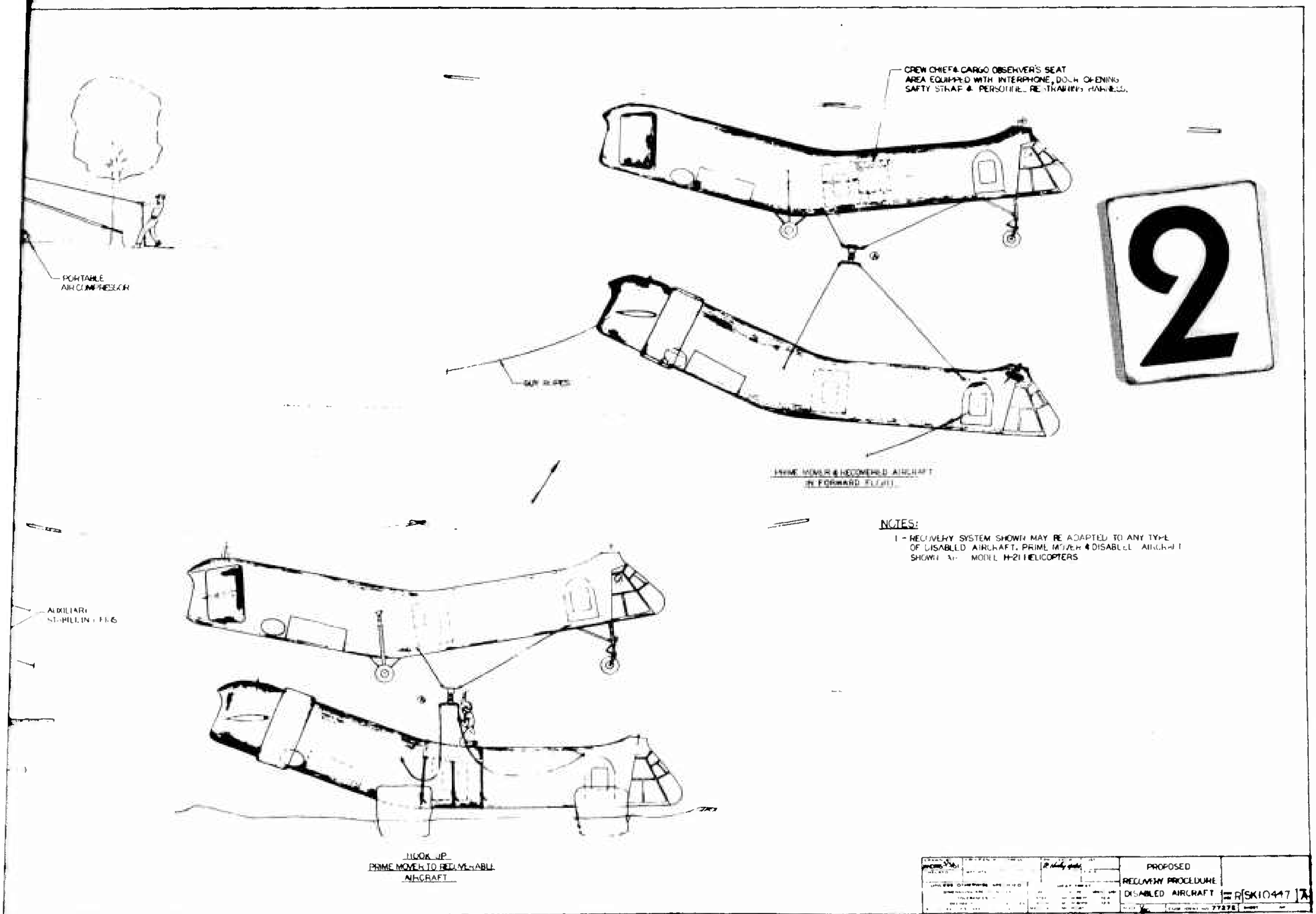


Ⓐ
CASE II-A-2 ILLUSTRATED
TYPICAL ALSO OF II-B-2

2

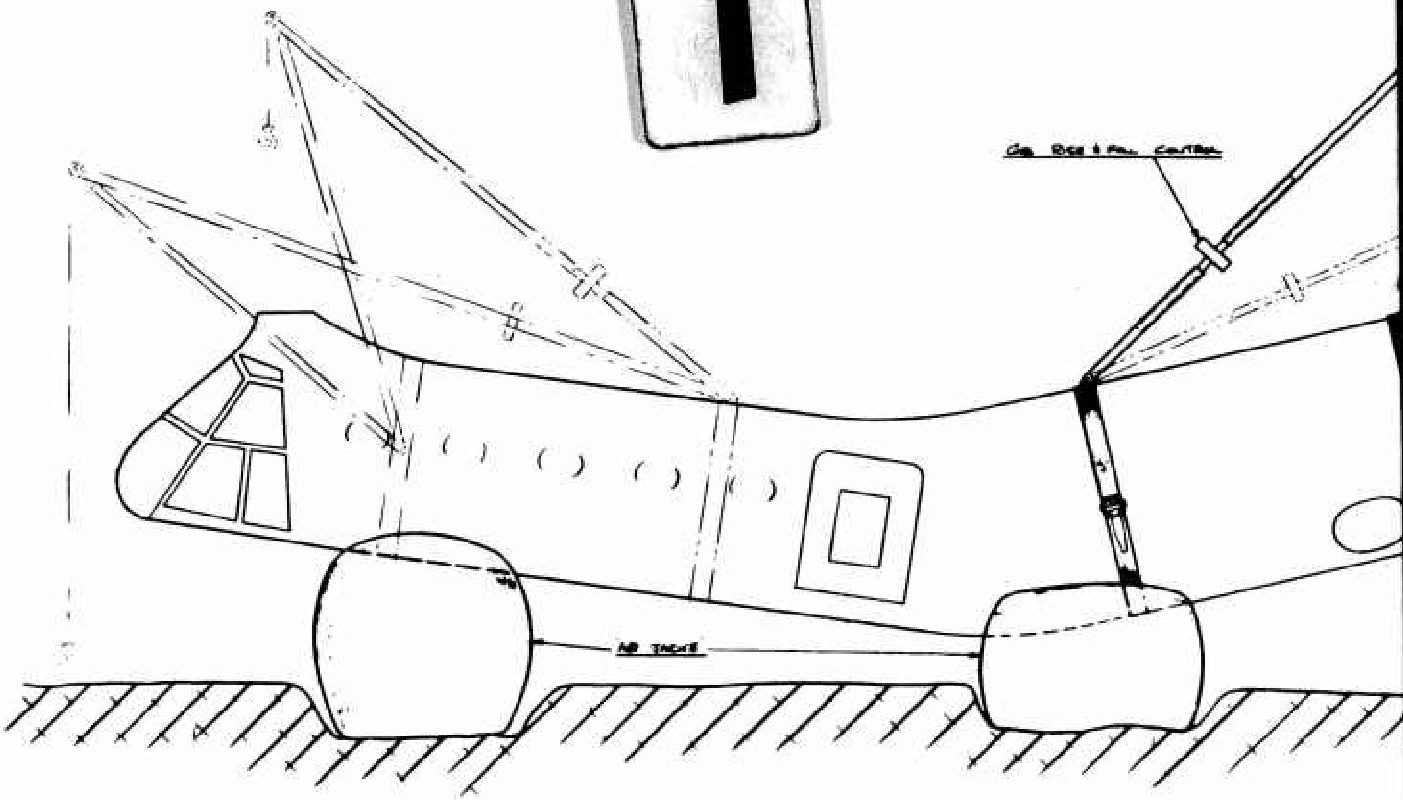

STOW PROPELLER FWD CABIN
(A) CASE II-A-2 ILLUSTRATED TYPICAL ALSO OF II-B-2
STOW PROPELLER AFT CABIN
(B) CASE II-B-4 ILLUSTRATED TYPICAL ALSO OF II-A-4
(9) SPONGERS (2x4) (WOOD)
(9) STRAPS
(2) MAT
PROPELLER STORED IN CABIN AFT
(C) CASE II-C-1 ILLUSTRATED
SLING CONFIGURATION
U/A
RECOVERED AIRCRAFT
SK10921
1:40
77272

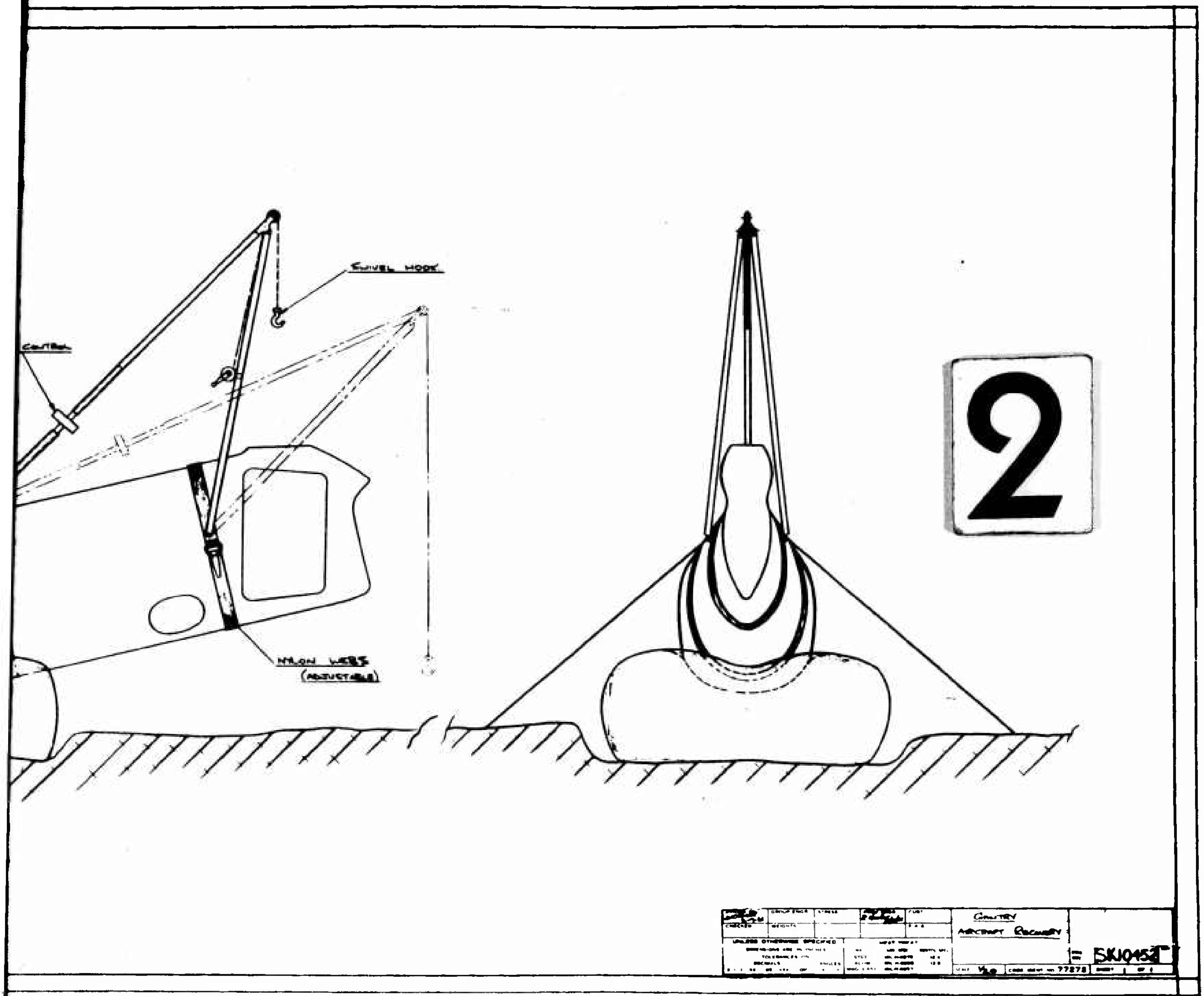

TRENCH DUG UNDER FUSELAGE
FOR PLACEMENT OF INFLATABLE
LIFT BAGS (TWO PLACES)
EACH BAG EQUIPPED WITH PRESSURE & RELEASE VALVES
PORTABLE
AIR COMPRESSOR
PREPARATION & RIGHTING CRIPPLED AIRCRAFT
1
RESTRAINING ROPE
AIRCRAFT HOISTING SLING
LEVEL TERRAIN
GUY ROPES
RIGGING
ATTITUDE
LIMITS
12° MAX
NOSE DOWN
PROVISIONS ARE INCORPORATED FOR
STACKING & LACING LIFT BAGS TOGETHER
FOR ADDITIONAL LIFT AS REQ'D.
AIRCRAFT IN RIGHTED POSITION FOR STRIPPING
& PREPARATION FOR RECOVERY



CREW CHIEF & CARGO OBSERVER'S SEAT
AREA EQUIPPED WITH INTERPHONE, DOOR OPENING
PORTABLE
AIR COMPRESSOR
GUY ROPES
PRIME MOVER & RECOVERED AIRCRAFT
IN FORWARD FLIGHT
NOTES:
1 - RECOVERY SYSTEM SHOWN MAY BE ADAPTED TO ANY TYPE
OF DISABLED AIRCRAFT. PRIME MOVER & DISABLED AIRCRAFT
MODEL H-21 HELICOPTERS
HOOK UP
PRIME MOVER TO RECOVERABLE
AIRCRAFT
PROPOSED
RECOVERY PROCEDURE
DISABLED AIRCRAFT
R SK10447
77272
2

1




SWIVEL HOOK
CONTROL
NYLON WEBS
(ADJUSTABLE)
2
GANTRY
AIRCRAFT RECOVERY

PRELIMINARY DESIGN OF RECOVERY SYSTEM
STRUCTURAL DESIGN DATA FOR RECOVERY SYSTEM

A review was made of all aircraft recovery cases specified in Table XII to select critical loads and system configurations from the standpoint of structural design requirements. The conditions listed in Table XIII A, below, represent a strength criteria envelope, on a preliminary design basis, for the load suspension system (SK10910, Sheets 1 and 2).

Design conditions for the fin kit (SK10910, Sheet 3) are listed below in Table XIII B. Two flight conditions are included: Condition I, a highly conservative envelope design condition for aerodynamic fin loads; and Condition II, which represents feasible operational flight loads. Two ground handling conditions are also considered, in view of field service loads which may be imposed on the fin kit components.

TABLE XIII

STRUCTURAL DESIGN CRITERIA, AIRCRAFT RECOVERY SYSTEM

A. SUSPENSION SYSTEM CRITERIA

Cond. No.	Recovered Load lbs.	(1) n (ULT)	(2) θ Degrees	(3) M in-lbs (ULT)	Suspension System Prime Mover	 Recovered Aircraft	 Ref. Chart
I	7,000	4.0	30	0	H-37	H-37 H-34 H-21	SK10917 SK10915 SK10916
II	7,000	3.0	30	41,800	H-37	H-21	SK10916
III	3,000	4.0	60	0	H-21 H-34	H-34 H-21 U-1A	SK10915 SK10916 SK10921
IV	5,200	4.0	40	0	H-37	H-19	SK10914

Notes:

(1) Load factor acts along the line of action of the recovered load.

(2) The recovery load shall be applied at all critical angles within a cone having an apex angle of θ. (Apex angles are determined by control power of prime movers.)

(3) Suspension system wind-up moment in yaw.

TABLE XIII

STRUCTURAL DESIGN CRITERIA, AIRCRAFT RECOVERY SYSTEM

B. FIN KIT CRITERIA

LIMIT FLIGHT LOADS

	Condition Number	V Knots	C_N	Fin Normal Force lb/fin
I.	Maximum Overspeed Note (1)	60	1.2	483
II.	Normal Cruise Speed Note (2)	50	0.7	194

GROUND HANDLING LOADS

Condition Number	Fin Kit Component and Criteria
	Fin
I	A 200 lb man standing on the fin surface while under a limit load factor of 2.0 (fin lying on uneven ground)
	Fin Support Tube
II	A 200 lb man standing on a fin support tube while under a limit load factor of 2.0 (load applied at tube mid span - ends pin supported)

Notes:

(1) Condition I is a conservative selection of aerodynamic parameters of speed and normal force coefficient, the latter associated with a maximum-efficiency symmetrical airfoil (not actually realized in the proposed recovery kit fin surface).

(2) Condition II is an operational fin requirement for a "flat plate" type fin at maximum C_N angle of attack (this corresponds to the recovery kit fin surface.

PRELIMINARY DESIGN OF RECOVERY SYSTEM
STRUCTURAL DESIGN DATA FOR RECOVERY SYSTEM

The following tabulation is a summary of the results of a preliminary stress analysis of the mechanical and aerodynamic yaw restraint systems.

The analysis data for the aerodynamic restraint system (vertical fin stabilizer kit) directly reflects the fin criteria stated in Table XIII.

Analysis of the mechanical yaw restraint system incorporates the weights, acceleration factors and torsional moment specified in Table XIIIA. However, the full kinematic range of load motion arbitrarily stated in the criteria has not been considered in the analysis presented in Appendix VII, Volume II, and summarized in Table XIVB. Nevertheless, analysis results would be altered in a relatively small degree by considerations of the full scope of arbitrary kinematic motion. Review of the analysis has indicated that weight and configuration of the yaw restraint connection would be unchanged from the design layout shown in Drawing SK10910, Sheet 2.

XIV. Summary of Stress Analysis Data - Aircraft Recovery System

(A) Yaw Restraint Spider Design Loads

Design Condition	V (Lbs)	H (Lbs)	S (Lbs)
	Upper Suspension System H-27 Prime Mover		
Cond. (I) = 4.0 (Ult.) W = 7,000 lb Θ = 30°	7,760	6,200	2,110
Cond. (II) = 3.0 (Ult.) W = 7,000 lb M_{Yaw} = 40,600 in.lb Θ = 30°	5,250	2,110	920
Cond. (III) n = 4.0 (Ult.) W = 3,000 lb Θ = 60°	2,980	4,160	1,740
	R (Lb)		
	Lower Suspension System H-19 Recovered Aircraft		
Cond. (IV) n = 4.0 (Ult.) W = 5,200 lb	20,800		

NOTE: Forces V, H, S and R are defined diagramatically on Page VII-2, Appendix VII, Volume II.

PRELIMINARY DESIGN OF RECOVERY SYSTEM
STRUCTURAL DESIGN DATA FOR RECOVERY SYSTEM

(B) Summary of Margins of Safety

Element	Design Condition	Ult. Design Load	Stress	Margin of Safety
		Yaw Restraint Spider		
Torque Plate Arm	I	M = 12,400 in.lb P_{Axial} = 32,720 lb	Combined Bending and Tension	+ .68
Weld Shear	I	q = 4,700 lb/in.	Shear	+ .12
Torque Plate Hub	I	M = 23,900 in.lb P_{Axial} = 19,500 lb	Combined Bending and Tension	+ .06
Key	II	V = 32,400 lb	Shear	+ .27
		Suspension Cable		
Cable	IV	20,800 lb	Tension	+ .10
		Fin Structure and Support Tubes		
Fin	Flight	M = 4,380 in.lb	Bending	+6.0
Fin	Flight	T = 1,820 in.lb	Torsion	+1.44
Fin	Ground Handling	M = 15,000 in.lb	Bending	+1.04
Fin	Ground Handling	P_{Normal} = 600 lb	Core Crushing	+ .14
Support Tube	Flight	P_{Axial} = 198 lb	Column Compression	+2.38
Support Tube	Ground Handling	M = 9,300 in.lb	Bending	+ .06
Support Tube	Ground Handling	M = 8,400 in.lb P_{Axial} = 320 lb	Combined Bending and Compression	+ .07

AIRCRAFT RECOVERY SYSTEM
PROPOSED FLIGHT TEST PROGRAM

A. GENERAL

The flight test program outlined below is planned as a functional qualification test of the aircraft recovery system described in the previous section of this report. Prior to flight, the strength of components or assemblies affecting safety of flight must be proof tested to at least 90% of design limit load. Proof test loads should be based on structural design criteria stated in this report (Page 114). Additionally, it is considered that functional behavior of certain components and assemblies of the recovery system must be ground tested prior to flight. Functional ground tests should include:

1. Reliability of release mechanism of suspension system.

2. Measurements of torsional spring rate of the mechanical yaw restraint cable systems (torsional spring rate is a function of the magnitude and direction of the load force vector, as well as cable suspension configuration).

3. Observation of kinematic motions of the mechanical yaw restraint system torque plates.

4. Determination of resistance to slippage of strap-on devices, such as the fin kit and protective mat (SK-10910).

It is anticipated that all functional ground tests and proof load tests, except the fin surface proof test, can be accomplished on a suitably moored flight test prime mover helicopter. Fin surface proof load testing should be more convenient with the fin supported in a horizontal position under shotbag or sandbag loading.

The flight test program is divided into three phases. Necessity for performing the third phase - field evaluation of the recovery system in adverse environmental conditions - is contingent upon findings of the basic qualification in the first two phases.

The test program phases are entitled as follows:

Phase I	-	Flight Evaluation of Aeromechanical Yaw Restraint System
Phase II	-	Flight Evaluation of Recovery System
Phase III	-	Field Evaluation of Recovery System

Prime mover helicopters and "recovered" aircraft test loads proposed for flight testing have been selected to provide a representative spectrum of prime mover-load combinations with a high degree of economy. The H-21 and H-34 helicopters cover the two significant prime mover types: tandem and single rotor.

AIRCRAFT RECOVERY SYSTEM
PROPOSED FLIGHT TEST PROGRAM

The loads selected for the test program would provide sufficient weight and aerodynamic flexibility to permit a comprehensive system evaluation. The program would progress from testing of relatively problem-free configurations to testing of prime mover-recovered aircraft combinations that have in the past imposed difficult operational problems.

B. EQUIPMENT AND INSTRUMENTATION

1. Prime Movers

   a. H-21
   b. H-34

2. Test Recovery Loads

   a. Long, slender, directionally-unstable load weighing 400 to 800 lb (such as rotor blade container or telephone pole).

   b. L-19 (complete aircraft), approximately 1,500 lb.

   c. L-20 (complete aircraft), approximately 3,000 lb.

   d. H-21 fuselage stripped to approximately 1,800 lb.

   e. H-21 fuselage stripped to approximately 3,000 lb.

3. Aircraft Recovery System (Per Vertol Drawing SK10910)

   a. Aerodynamic yaw restraint (fin kit).
   b. Mechanical yaw restraint (prime mover aircraft recovery sling).
   c. Load suspension rigging equipment.

4. Chase Helicopter - (The alternate "prime mover" helicopter can be used as the chase helicopter)

5. Instrumentation

   a. Motion Picture Photo Coverage

      (1) Ground Camera
      (2) Chase Camera
      (3) Prime Mover Mounted Camera

(a) This camera will be mounted on the underside of the prime mover to (1) record pitch, roll and yaw motion of the prime load relative to the prime mover, (2) motion of the upper and lower plates of mechanical yaw restraint system.

b. Prime Mover Flight Instrumentation

(1) Airspeed
(2) Outside air temperature
(3) Altitude
(4) Rotor rpm
(5) Longitudinal stick position
(6) Lateral stick position
(7) Collective pitch position
(8) Pedal position
(9) Manifold Pressure
(10) Prime Mover Pitch Attitude
(11) Prime Mover Roll Attitude
(12) Prime Mover Yaw Angle
(13) Prime Mover Pitch Rate
(14) Prime Mover Roll Rate
(15) Prime Mover Yaw Rate
(16) Normal Acceleration

6. Communication

a. Between pilot of Prime Mover and

(1) Flight Crew Observer
(2) Ground Observer
(3) Chase Observer

C. TEST PROGRAM

1. Phase I - Flight Evaluation of the Aeromechanical Yaw Restraint System

a. Flight Evaluation of Aerodynamic Yaw Restraint

(1) Suspend a long, slender, directionally-unstable, high weight-density load of 400 lb to 800 lb at least 40 ft below the hook. Evaluate the stability characteristics of the load with and without the directional fin kit. It is intended that the light load suspended far below the prime mover will permit evaluation of the aerodynamic yaw restraint kit

without jeopardizing flight safety. The load should be an expendable item and the flight test program should be conducted over an area that would permit emergency release at any time. A speed build-up program should be followed for evaluation runs of 40, 50 and 60 knots for climbing, level and descending flight regimes. Complete photo, instrument and observer recording should be maintained. Observer comments should be evaluated following each run before continuing the flight program.

b. Preliminary Flight Evaluation of Combined Aeromechanical Yaw Restraint System

(1) Suspend the same load as in Part "a", complete with fins and mechanical yaw restraint hook to simulate the H-21 recovery mission.

(2) Evaluate the Characteristics of the Load in Hover

(a) Introduce small longitudinal, lateral and directional disturbances for the following wind conditions: 10 knot headwind (0^o), and 10 knot wind from 0^o to 180^o from the left (45^o increments).

(b) Vertical climb and descent of 50 feet for the above wind conditions.

(3) Evaluate the characteristics of the load in transition and forward flight

(a) Observe the load flight characteristics through transition and stabilized flight at 40 knots.

(b) Introduce small longitudinal, lateral and directional disturbances for 40 knot level, climbing and descending flight. Repeat for 50 and 60 knots.

2. Phase II - Flight Evaluation of Recovery System

a. Repeat the flight evaluation outlined in Phase I for the following loads:

(1) L-19 without wings and tail, with complete aeromechanical recovery system installed.

(2) L-19 with wings and tail (complete aircraft) with mechanical yaw restraint only.

(3) L-20 without wings and tail, with complete aeromechanical recovery system installed.

(4) L-20 with wings and tail, with mechanical yaw restraint only.

(5) H-21 1800 lb G.W. with complete aeromechanical recovery system installed.

(6) H-21 3000 lb G. W. with complete aeromechanical recovery system installed.

3. Phase III - Field Evaluation of Recovery System

a. The purpose of Phase III testing is to formulate ground and air crew operating procedures for aircraft recovery.

b. An illustration of suggested field preparation techniques for a downed H-21 is shown in SK10447 in this report.

c. Field evaluation recovery load

(1) H-21 fuselage

(a) Contingent upon economic availability of expendable test loads, the H-21 hull is suggested as the recovered aircraft for the field evaluation. The H-21 will provide sufficient operational complexity for a comprehensive evaluation of adaptability of the Vertol SK10910 recovery kit. Furthermore, the H-21 is suitable for evaluation of load preparation techniques for the aircraft recovery operation under adverse conditions.

d. Field evaluation terrain

(1) Flat, firm and unobstructed terrain (this evaluation will be accomplished in the Phase II "Flight Evaluation of Recovery System".

(2) Sloping Terrain

(a) For the sloping terrain evaluation, the H-21 hull would, due to its length, provide a

difficult lift-off problem when situated with the longitudinal axis down the grade.

(b) When situated along the grade of sloping terrain, the H-21 without landing gear will tend to roll downhill due to the prime mover rotor downwash.

(3) Soft, Flat Terrain (e.g., mud flats)

(a) This terrain introduces the problem, among others, of preparing the hull for lift-off to avoid "unsticking" forces of mud and mire (this problem also applies to downed aircraft frozen to the ground).

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Unclassified Report

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